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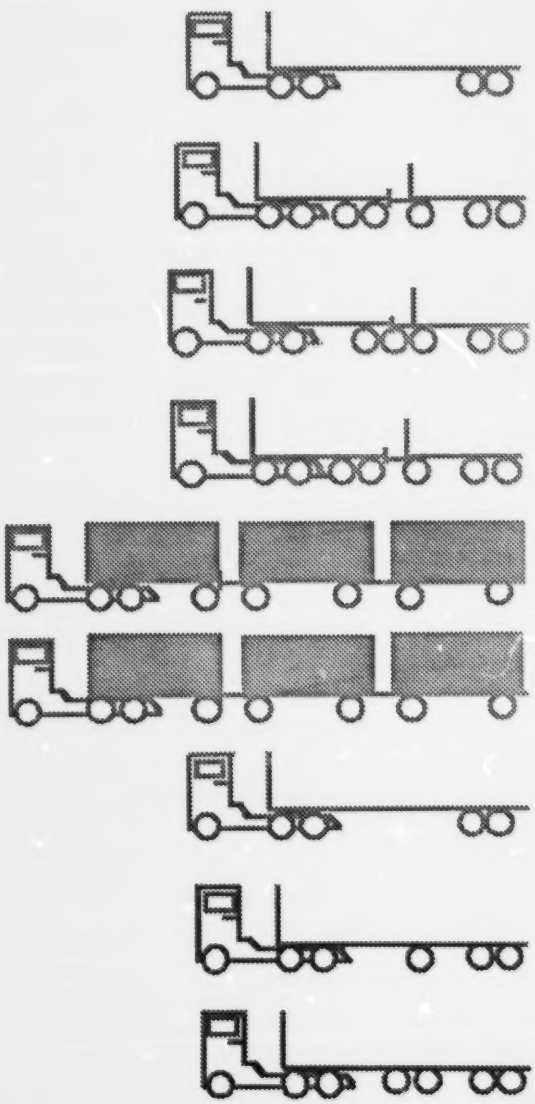
Procedures for Test of Baseline and Additional Vehicles



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Procedures for Test of Baseline and Additional Vehicles

J.R. Billing
Head,
Commercial Vehicles Section

W. Mercer
Research Engineer

W.R. Stephenson
Research Engineer

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Authors (name, title and/or organization):
J.R. Billing, Head, Commercial Vehicles Section; W. Mercer, Research Engineer; W.R. Stephenson, Research Engineer

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Abstract:
A substantial program of full-scale heavy truck dynamic testing was undertaken in 1985 on behalf of the CCMTA/RTAC Vehicle Weights and Dimensions Study by the Ontario Ministry of Transportation and Communications. Six baseline vehicle configurations and one four-axle semitrailer configured to provide three additional vehicle configurations were tested.

This report presents detailed information on vehicle preparation, test procedures, data processing, and other factors common to the test of the nine configurations. It is intended to supplement the individual vehicle test reports, which only discuss procedures where they might have differed in some respect from the standard described herein.

Key Words: truck testing, offtracking, truck turning, air brake system, braking, truck dynamic tests, rearward amplification, rollover, lane change, tilt test

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ABSTRACT

A substantial program of full-scale heavy truck dynamic testing was undertaken in 1985 on behalf of the CCMTA/RTAC Vehicle Weights and Dimensions Study by the Ontario Ministry of Transportation and Communications. Six baseline vehicle configurations and one four-axle semitrailer configured to provide three additional vehicle configurations were tested.

This report presents detailed information on vehicle preparation, test procedures, data processing, and other factors common to the test of the nine vehicle configurations. It supplements the individual vehicle test reports, which only discuss procedures which differ from the standard ones described here.

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1/ INTRODUCTION

The CCMTA/RTAC Vehicle Weights and Dimensions Study is examining the effects of weight and dimension parameters on heavy truck stability and control, and on pavement response. The objective is to compile technical information that, with an earlier study of the effects of heavy trucks on bridge loading [1], would provide a basis for the provinces to amend their truck weight and dimension regulations. The goal is to simplify interprovincial trucking through greater uniformity in these regulations.

The truck population of Canada was surveyed, and six generic families were defined based on the number of trailers and hitching methods. One vehicle in common use in at least some provinces was defined as representative of each family and designated as the baseline vehicle configuration. Additional vehicles of interest were also defined. The Ontario Ministry of Transportation and Communications (MTC) was asked to test the six baseline vehicles and a four-axle semitrailer that could be configured to provided three additional vehicle configurations.

This report describes the test procedures employed in the tests of these vehicles. It presents those portions of the test program which were common to the test of all vehicles. It supplements the detailed test reports of each vehicle [2-10] and the summary report [11].

2/ TEST OBJECTIVES

Six baseline vehicle configurations, which are all in common use in some Canadian provinces, were defined. Each baseline vehicle served as a yardstick against which variations in weight, dimension, or equipment were to be evaluated by means of a comprehensive series of computer simulations.

The primary objective of the test program was to assemble a body of technical and visual data that described the stability and control characteristics of the baseline vehicles with respect to certain performance measures. These tests would be used as a background to complement the findings of the computer simulation. Test manoeuvres were conducted to examine the following:

- turning performance;
- the air brake system;
- lateral/directional stability characteristics of an empty vehicle on a low-friction surface, with and without braking;
- lateral/directional response characteristics of a loaded vehicle on a high-friction surface;
- steady-state roll characteristics of a loaded vehicle on a high-friction surface;
- dynamic stability characteristics of a loaded vehicle on a high-friction surface;
- trailer sway.

Several additional vehicle configurations were also defined, three of which were also subjected by MTC to exactly the same tests as the baseline vehicles. The objective of these tests was to highlight the characteristics of interest of these particular vehicles, again, to complement the computer simulation.

A secondary objective was to conduct computer simulations using the measured test inputs and actual vehicle unit properties to demonstrate that simulation can represent vehicle responses for a wide range of vehicles and test manoeuvres.

3/ TEST VEHICLES

The set of vehicles to be tested was defined and provided to MTC. The baseline vehicle configurations are shown in Figure 1, and the additional vehicle configurations are shown in Figure 2. Detailed information on each vehicle may be found in its own test report [2-10]. The baseline vehicles are also described in a summary report [11].

4/ TEST SITES

4.1/ MTC Commercial Vehicle Test Facility (Centralia)

Empty vehicle, low-friction surface tests were conducted at the Ministry of Transportation and Communications (MTC) Commercial Vehicle Test Facility (Centralia). This test facility is located at Huron Industrial Park, Centralia, 45 km (28 mi) north of London, Ontario. The test track, shown in Figure 3, is a former airfield runway 1000 m long by 50 m wide (3281 by 164 ft). It has a test area, approximately 350 m (1148 ft) long, of smooth asphalt, with a smooth approach 150 m (492 ft) long. The test area includes a high-friction surface 150 m (492 ft) long with a dry skid number of about 96, and a low-friction surface 200 m (656 ft) long with a wet skid number of about 18 to 24. A sprinkler system is used for continuous wetting of this surface. There is also a curved entry, radius 86.7 m (284.4 ft), into the low-friction surface. The low-friction surface is abutted by smooth shoulders in case total loss of vehicle control should result in the vehicle sliding off the test area. There is also a low-friction lane on the approach, which can be used effectively to provide a split-friction surface. Vehicle speed through the high-friction test area is limited by the available approach length and tractor power to about 75 km/h. Speed through the low-friction test area is limited to about 60 km/h, to avoid hazard if the vehicle should spin after the safety cables become engaged as a result of loss of control.

The test facility also has about 2000 m^2 (21 529 ft^2) of work space for vehicle preparation and storage. It includes basic shop facilities, an electronics lab, office space, and a ground station for data acquisition and processing.

4.2/ Transport Canada Motor Vehicle Test Centre (Blainville)

Loaded-vehicle, high-friction surface tests were conducted at the Transport Canada Motor Vehicle Test Centre, located at Blainville, Quebec, 35 km (22 mi) north of Montreal. This facility was made available for the study by Transport Canada. The centre has a 6.5 km (4 mi) high-speed track, with high-speed entrance to and exit from the large vehicle dynamics area (VDA), as shown in Figure 4. The section of the VDA parallel to the high-speed track is about 400 m (1312 ft) long. The ASTM E274-77 dry pavement skid number of the VDA at 72 km/h and 30°C is about 90.

Vehicle tests conducted by the ministry were confined to the high-speed track and the VDA. In addition, tilt tests were conducted by others, using a tilt table installed at Blainville for the study [12].

5/ TEST PROGRAM

5.1/ Vehicle Preparation

Two tractors were used as power units for all combinations. A 1976 Freightliner 6x4 was used for all except two turning tests. A 1974 4x2 International Loadstar was used for these tests.

The MTC Freightliner shown in Figure 5 has been used in many previous test programs and was already fully instrumented for the requirements of these tests. It is a cab-over-engine type with integral sleeper, powered by a Detroit Diesel V-12 engine rated at 465 bhp at 2100 rpm. The front axle is rated at 8182 kg (18 000 lb), and the tandem drive axles use a Hendrickson RTE-440 walking beam suspension rated at 20 000 kg (44 000 lb). The wheelbase is 3.50 m (138 in), the tandem axle spread is 1.83 m (72 in), and the drive axle wheel track is 2.44 m (96 in). The fifth wheel is installed 0.20 m (8 in) forward of the midpoint of the drive tandem. The normal operating weight of the Freightliner was about 9790 kg (21 540 lb), including driver and typical quantities of fluids. The Freightliner is somewhat atypical of late-model tractors used in interprovincial trucking, where the typical front axle rating is 5455 kg (12 000 lb), drive tandem spread is 1.52 m (60 in), and weight is 7730 to 8409 kg (17 000 to 18 500 lb).

The front axle used Michelin XZA radial tires, load range G, size 11R-24.5, and the drive axles used Michelin XM+S4 radial tires, load range G, size 11R-24.5. The tires were inflated to the manufacturers recommended pressure of 689 kPa (100 psi) for the tire full rated load. This pressure was used for all tests. It represents the common practice of not reducing tire pressure when the truck runs empty. Tires were installed new and used continuously for tests with various combinations until about half the drive axle tire tread had been consumed. At this point, they were replaced with tires from the same production batch as the original tires for the balance of the test program.

The MTC International Loadstar shown in Figure 6 was used for two turning tests because it allowed the Freightliner to be available for other tests and vehicle preparation activities critical to the test schedule. This tractor is not typical at all of tractors which would haul the test trailers in interprovincial trucking. However, with a 3.81 m (150 in) wheelbase, and a fifth wheel 0.015 m (6 in) forward of the drive axle, its turning characteristics were regarded as sufficiently close to those

of the Freightliner that the substitution was acceptable. Other specifications of this tractor are irrelevant to the test program and, therefore, are not presented.

The test trailers were equipped with the following:

- new tires
- outriggers
- safety cables
- instrument packages
- load

All trailers and converter dollies used Michelin XZA radial tires, load range H, size 11R-22.5, from the same production batch. The tires were installed new and inflated to the manufacturers recommended pressures of 689 kPa (100 psi) for the tire full rated load. Tires were run a variable distance before the test, ranging from zero for two airlift axles and three dolly axles to 500 km (350 mi) for vehicles whose first test was at Blainville. Once installed on a vehicle unit, tires were not changed. Thus, vehicle units used for more than one vehicle configuration experienced progressive tire wear as the tests proceeded. Most trailer tires showed little wear as a consequence of the tests, although some did experience severe wear in unusual patterns. However, no tire wore anywhere close to typical rejection limits.

Detachable beam-type underslung outriggers were specially designed, and three sets were fabricated for these tests. The outrigger consisted of a centre section which clamped to a trailer's frame rails and was bolted through the deck around the frame rails. Extension sections were pin jointed to the centre section. Each extension had a wheel fitted with a super single tire, used because it was available in MTC inventory. Wheel height was adjustable to compensate for different ground clearances of trailer frame rails. The outrigger assembly is shown in Figures 7 and 8. The van-type trailers used in the triple combinations were basically monocoque construction and required an adapter to be mounted beneath the floor subframe, forward of the stub chassis, to accept and distribute outrigger loads. The outriggers were bolted to this adapter and secured by the triangulated tension chains, which reacted longitudinal load at outrigger touchdown, as seen in Figure 8. One of two pairs of conventional frame-type outriggers already available to MTC was used with the four-axle semitrailer that made up the additional vehicle configuration, as shown in Figure 9. Both sets of outriggers were set with a ground clearance of 0.25 to 0.30 m, which corresponds to a trailer roll angle

of 6 to 7° at outrigger touchdown. Some local strengthening of flatbed trailers was conducted so that the structure could resist touchdown loads without permanent deformation.

High-speed dynamic testing of combination vehicles on a low-friction surface carries the hazard of tractor or dolly jackknife, or trailer swing. To prevent damage from such loss of control, high-strength braided wire safety cables were installed between each consecutive pair of vehicle units to limit articulation angles to about 20°. The Freightliner had an auxiliary frame bolted to its frame rails for attachment of safety cables. Heavy-gauge steel lugs were welded onto each trailer and dolly at appropriate locations to limit the articulation properly. A typical safety cable installation is shown in Figure 10.

Each vehicle was tested nominally empty, which was without payload but equipped with instrumentation, outriggers, and safety cables. Each trailer therefore weighed about 1500 to 1800 kg (3300 to 4000 lb) more than it would on the highway.

Each vehicle was also tested at one nominal gross weight. This gross weight was achieved by loading trailers with concrete blocks, 53.3 x 70 x 121.9 cm. (21 x 24 x 48 in.) in size, weighing about 936 kg (2060 lb) each. Blocks were tightly secured with chains. It was specified in the study that the front axle load on all combinations not exceed 6000 kg (13 200 lb) and that all other axles be loaded to approximately 8000 kg (17 600 lb). Blocks were loaded in groups of one or two layers. Longitudinal and vertical location of the loaded trailer centre of gravity, and its roll and yaw moments of inertia, depended upon the trailer construction, number of axles, type of outrigger used, and load block locations.

Before testing, the vehicle was assembled in its test configuration, and the following additional measures were taken:

- The vehicle was checked for general mechanical fitness.
- Brake slack was checked and adjusted as necessary.
- Tire inflation pressure was set.
- Relevant vehicle dimensions were measured.
- The vehicle was weighed by axle, empty and loaded.
- Detailed measurements and an inventory of trailer structural numbers, fittings, and other components were made.
- Instrumentation was installed, as described in Section 5.2.
- Still photographs and video were taken of the vehicle as a whole, parts

thereof, and instrumentation installations.

5.2/ Instrumentation

The MTC Freightliner has been used in many previous test programs. As a consequence, it was already equipped to measure the following driver inputs and vehicle responses:

- road wheel steer angle;
- speed;
- distance travelled;
- brake on/off;
- brake treadle valve pressure;
- brake chamber pressures;
- roll, pitch, and yaw angles;
- roll, pitch and yaw rates;
- longitudinal, lateral, and vertical accelerations measured from an inertial platform;
- lateral load at the fifth wheel;
- an optical sensor for precise speed and position measurements;
- others, not required for this test program, such as steering wheel angle and rate, other wheel speeds, etc.

The heart of the instrumentation was the Humphrey Model CF18-0907-1 gyro package, shown in Figures 11 and 12. It contains three angular rate transducers to give the roll, pitch, and yaw angular rates; three directional gyros that provide the roll, pitch, and yaw (or heading) angles; and a stabilized inertial platform on which accelerometers are mounted to measure the three linear accelerations. For these tests, only yaw rate, roll and yaw angles, and longitudinal and lateral accelerations were recorded. At the start of a test run, the inertial platform is caged or locked to its support frame. At some initial point, it is uncaged or released. The initial output from the package therefore represents the vehicle attitude as zero, and subsequent outputs through the run are all relative to this initial situation. All tests were conducted so that the vehicle was travelling initially at a steady speed in a straight line, to the greatest extent possible. The linear accelerations essentially were true values measured parallel to the vehicle position at the instant the gyro was uncaged. As the vehicle moved through a run, these outputs reflected any vehicle attitude changes due to the ground, such as changes in grade or crossfall and vertical curvature. Corrections may be necessary for this, as described in Section 5.5. The rate transducers have a resolution of 0.01°/s. The directional gyros have a nominal resolution

of 0.09° and an accuracy of 0.25°, which is the tolerance of the gyro alignment controller. The yaw gyro additionally has a steady drift due to rotation of the earth, depending upon latitude of the test site and vehicle heading, which was also corrected as described in Section 5.5.

Road wheel steer angle was measured using a Spectrol model 139-0-0-502 continuous film rotary potentiometer with essentially infinitesimal resolution. It was mounted on the steering kingpin bushing of the left front wheel, to measure rotation of the spindle relative to the bushing. This measurement was used directly as the steer angle, without any correction for kingpin inclination, offset, caster, camber, or Ackerman effect.

The brake light switch was used to provide brake on/off status. This was converted to a single bit and included with other vehicle status data in a digital word output by the data acquisition system, as described in Section 5.4.

Brake treadle valve pressure and pressure in the left brake chamber of the lead axle of the tractor drive tandem were measured using Celesco Model PLC-200G pressure transducers.

Vehicle speed was measured using an Airpax Model 087-304-0044 zero velocity magnetic pickup, which counted the passage of notches in the brake drum of the right front wheel. There were 60 milled notches in the drum. A tachometer signal conditioning card provided a continuously varying voltage proportional to notch passage rate. The cumulative notch passage count was also conditioned to provide a continuously varying voltage proportional to distance travelled. When the voltage reached full scale, it automatically reset to minus full scale. The output resulting from driving at a steady speed, therefore, was a continuous inverted N wave. Both these measurements were calibrated simply by marking the bottom of the right front tire with chalk, driving the vehicle forward slowly for exactly 10 wheel revolutions, and then measuring the distance travelled.

Lateral load at the tractor fifth wheel was measured using a fifth wheel specially modified by MTC, shown in Figure 13. A long trunnion bar was obtained, and the fifth wheel mounts were modified to accept two cylindrical load cells which were specially fabricated and calibrated by the MTC Research Laboratory. The load cells were captured between the fifth wheel pillow blocks and the retainers by nuts which tensioned the trunnion bar, as shown in Figure 14. A compressive preload of about

22.3 kN (5000 lb) was put into each load cell. The load cells, therefore, gave an output proportional to trailer lateral load parallel to the fifth wheel trunnion bar. A load to the right would increase the left load cell output and correspondingly reduce the right load cell output. It was found that changes in vertical and longitudinal load, and perhaps roll moment, resulted in bending of the trunnion bar, which increased the output of each load cell. Net lateral load, therefore, was obtained from the mean difference of the individual load cell calibrated outputs.

The tractor was equipped to control the instrumentation either by an automatic or a manual start that uncaged the gyro package, initialized the distance counter, commanded the data acquisition system through a calibration sequence, and finally returned it to data status. The automatic start was triggered by means of a downward facing optical sensor beneath the tractor, which responded to reflected light from the ground beneath. A highly reflective patch of tape was placed on the ground a suitable distance ahead of the point where the test manoeuvre was to be made. This meant the data sequences for similar runs were similar, which simplified the development of computer data processing. Since the optical sensor would trigger on any reflective patch, it was normally inactive and was armed by the driver on the final approach just before the start patch.

Each trailer was instrumented to measure the following basic responses:

- articulation angle
- lateral acceleration
- roll angle
- outrigger touchdown

Articulation angle of the lead trailer relative to the tractor was measured by means of the Celesco Model DV-301-150 pull-cord transducer shown in Figure 15. The transducer was fixed on the right-hand side of the tractor, and the pull cord was extended to clip on the left front corner of the trailer. Articulation of the trailer resulted in extension or retraction of the pull cord. The transducer provided a voltage output proportional to the pull-cord extension. Because trailer geometry varied, it was necessary to calibrate articulation angle against transducer output for each trailer. The procedure for this was as follows:

1/ Park the vehicle in a straight line on a level surface.
2/ Measure distances AE, ED, BE, and EC in Figure 16, with the trailer straight.
3/ Zero the transducer conditioned output.

4/ Record transducer positive and negative full-scale electronic calibrations.
5/ Measure distances BD and CD in Figure 16.
6/ Drive forward some distance, steering to the left, until transducer output is about 10% of full scale, then record transducer conditioned output and distances BD and CD.
7/ Repeat step 6 for additional increments of 10% of full scale until full scale is reached, then steer to the right until full scale to the right is reached, then return to a straight line.
8/ Compute articulation angles from the geometric measurements and obtain a nominal full-scale calibration for articulation angle from the slope of a least squares linear fit of articulation angle to transducer conditioned output.

Because articulation angles were limited to about 20° by the safety cables, all calibrations were linear within the resolution of the transducers and data acquisition system.

Articulation angle of other trailers relative to a towing unit was obtained by direct measurement, using a Spectrol model 140-0-0-502 small rotary potentiometer set inside a powerful permanent magnet. Because all towing units had fifth wheels without a continuous trunnion bar, there was space to mount the magnet directly onto the bottom of the trailer kingpin. A hole was drilled through the front flange of the fifth wheel, and a wire reference arm was put through the hole and fastened to the potentiometer rotor. An installation is shown in Figure 17. The potentiometer measured trailer articulation angle directly and, because of the wire arm location, was insensitive to longitudinal bumping of the trailer due to free play of the kingpin in the fifth wheel jaws. Resolution of the potentiometer was 0.5°. The magnet used for this installation was an Eriez No. 277 with a clamping force of 44.5 N (160 oz) and a weight of only 57 g (2 oz). The magnet was powerful enough not only to remain attached to the greasy kingpin, but also to stay fixed in position, through some rather violent manoeuvres.

Lateral acceleration was measured with a Columbia Model SA-107 accelerometer mounted to the deck of the trailer. Unlike lateral acceleration of the tractor, which was measured from an inertial platform, this transducer was sensitive to roll of the trailer and measured a component of the gravitational acceleration due to roll. This was corrected, as described in Section 5.5.

Trailer roll angle was measured using a Humphrey Model VM02-0128-1 vertical gyro, the same model that was built into the gyro package in the tractor. The exception was the rear trailer of the triple combinations, where a Humphrey Model RT03-0502-1 rate transducer was installed, also the same model built into the tractor gyro package. Roll angle of this trailer was computed by integration of roll rate.

An outrigger touchdown indicator was set up by strain gauging the tabs to which the outrigger tension chains were attached, as shown in Figure 18. When an outrigger touched down, the change in chain tension resulted in a strain response offset. Left and right outriggers were rigged in a single channel so that right-side touchdown resulted in a positive response and left-side touchdown resulted in a negative response. However, these signals were noisy, tended to drift, and were ultimately not needed because the roll angle characteristic response gave a good indication of outrigger touchdown.

Additional Celesco model PLC-200G pressure transducers were installed in brake chambers of trailers and dollies for the brake tests, as shown in Figure 19. Generally, one transducer was installed for each axle of the trailer.

A single package containing the accelerometer and roll gyro, signal conditioning, multiplexer, and power supply contained the bulk of the instrumentation for each trailer. This package was mounted on the deck of the trailer midway between the kingpin and the centre of the trailer axles. It is shown in Figure 20, and its contents are shown in Figure 21.

Each A-dolly was instrumented to measure the hitch articulation angle by means of a Spectrol model 140 rotary potentiometer set inside a powerful permanent magnet, and a flexible reference arm, as shown in Figure 22. Each B-dolly was instrumented to measure its axle steer angle by means of a Spectrol model 139 rotary potentiometer, as shown in Figure 23. Each dolly also had an accelerometer installed to measure lateral acceleration at a point close to the trailer kingpin.

The data acquisition system described in Section 5.4 had a capacity of 42 channels, of which up to 36 were used. Fourteen channels were allocated to the tractor multiplex for the entire test program. Ten channels were allocated to the multiplexer in the instrument box on the lead trailer, of which three were used for dynamic data; five, for pressure transducers

used during brake tests; and two spares. Twelve channels were allocated to the multiplexer in the box on a second trailer, and for triples the third trailer transducers were wired into this box. The triples, therefore, used almost the full capacity of the multiplex, and every other vehicle tested used a subset of the data channels, depending upon its configuration. The location and type of instruments and their allocation to the multiplex system are all presented in Table 1. Channels 1 to 17 and 20 to 24 were used for semis; channels 1 to 32 were used for doubles; and all 36 channels were used for triples.

5.3/ Detailed Test Procedures

The tests and demonstration conducted on all test vehicle configurations are broken down into four categories:

1/ Stationary
- Air brake system
- Tilt test

2/ Low-Speed Turns
- Steady-state offtracking
- Right-hand turn
- Channelized right turn

3/ Low-Friction Dynamic, Empty Vehicle
- Straight-line braking demonstration
- Evasive manoeuvre

4/ High-Friction Dynamic, Loaded Vehicle
- Sinusoidal steer
- Lane change
- Straight-line driving
- Steady circular turn

The following subsections present the rationale for each test and provide details of the procedure followed. The output expected from each test is presented in the corresponding subsection of Section 5.5, where details of the data processing are discussed.

For all driving tests where a sequence of runs at increasing speeds was required, speeds were selected that resulted from the driver using full throttle in the appropriate gear. The engine speed control then acted as

Table 1/ Instrumentation Installed

No	Measurement	Instrument	Full Scale
1	Tractor steer angle	Spectrol 139 potentiometer	25.02°
2	Tractor roll angle	Humphrey CF18-0907-1 gyro package	8.85°
3	Tractor lateral acceleration	Kistler 303B accelerometer	0.957 g
4	Tractor yaw rate	Humphrey RT03-0502-1 angular rate transducer	38.7°/s
5	Tractor longitudinal acceleration	Kistler 303B accelerometer	0.974 g
6	Tractor speed, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	104.8 km/h
7	Tractor distance, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	56.3 m/ramp
8	Tractor fifth wheel load, left-hand side	MTC load cell	9890 lb
9	Tractor fifth wheel load, right-hand side	MTC load cell	10290 lb
10	Tractor treadle valve pressure	Celesco PLC-200G	100 psi
11	Tractor brake pressure, axle 2 Left	Celesco PLC-200G	99.80 psi
12	Tractor lateral acceleration at fifth wheel	Columbia SA-107 accelerometer	0.996 g
13	Tractor yaw angle	Humphrey CF18-0907-1 gyro package	17.73°
14	Trailer 1 articulation angle	Celesco pull cord DV-301-150	Varies
15	Trailer 1 lateral acceleration	Columbia SA-107 accelerometer	0.995 g
16	Trailer 1 roll angle	Humphrey VM02-0128-1 vertical gyro	8.90°
17	Trailer 1 outrigger touchdown	Strain gauge bridge	1.0 V
18	Dolly 1 hitch angle	Spectrol 139 potentiometer	25.0°
19	Dolly 1 lateral acceleration	Columbia SA-107 accelerometer	0.996 g
20	Brake pressure, axle 4 right	Celesco PLC-200G	104.96 psi
21	Brake pressure, axle 5 right	Celesco PLC-200G	101.06 psi
22	Brake pressure, axle 6 right	Celesco PLC-200G	102.07 psi
23	Brake pressure, axle 7 right	Celesco PLC-200G	101.93 psi
24	Brake pressure, axle 8 right	Celesco PLC-200G	106.79 psi
25	Spare		
26	Spare		
27	Trailer 1 articulation angle	Spectrol 140 potentiometer	22.8°
28	Trailer 2 lateral acceleration	Columbia SA-107 accelerometer	0.980 g
29	Trailer 2 roll angle	Humphrey VM02-0128-1 vertical gyro	8.91°
30	Trailer 2 outrigger touchdown	Strain gauge bridge	1.0 V
31	Dolly 2 hitch angle	Spectrol 139 potentiometer	25.0°
32	Dolly 2 lateral acceleration	Columbia SA-107 accelerometer	0.993 g
33	Trailer 3 articulation angle	Spectrol 140 potentiometer	22.7°
34	Trailer 3 lateral acceleration	Columbia SA-107 accelerometer	0.986 g
35	Trailer 3 roll rate	Humphrey RT03-0502-1 angular rate transducer	80.85°/s
36	Trailer 3 outrigger touchdown	Strain gauge bridge	1.0 V

a limiter to hold speed to the required value. This was beneficial, as manual speed control at the stability thresholds proved to be difficult to maintain because of vehicle cab vibration, high drag during an aggressive manoeuvre, and driver work load. The actual controlled speeds used in the various tests were 34, 40, 47, 55, 63, 72, 77, 80, 84, 89, and 94 km/h. The nominal speeds used by the driver were in miles per hour and differed somewhat from the actual values at the highest speed.

All tests except for the two right turns were conducted with outriggers and safety cables installed.

5.3.1/ Offtracking

The interaction of large trucks with highway geometrics was not specifically included in the study. It is, however, perhaps the most evident manifestation of increasing truck size to the motoring public in urban communities. Large trucks simply take more space and time to make turns than smaller trucks and, thus, appear to impede traffic. Three tests, therefore, were added to illustrate the space requirements needed for turns and to demonstrate the swept paths.

Steady-state offtracking is the most widely understood measure of the turning capability of large trucks. In normal driving, however, a steady-state offtracking situation would only likely be encountered in a 270° cloverleaf turn on a freeway ramp. In many cases these ramps are made up not of a principal circular arc with entry and exit spirals, but of several spirals and curves to accommodate the local space and terrain requirements. Trucks using these less regular ramps may not reach a true steady state. Nevertheless, steady-state offtracking remains a useful ranking of the space required to turn a large truck, though it may be somewhat misleading for some turns.

Steady-state offtracking was determined by driving the loaded vehicle on a high-friction surface at low speed, less than 5 km/h, in a circle of radius 29.87 m. The turn was made with the truck on the inside of the circle with the tractor outer front wheel following the circumference. The vehicle traversed the circle until steady-state offtracking had been achieved and continued to about one full revolution. Measurements were then taken from the centre of the circle to each axle's innermost tire. The test was repeated in the opposite direction to determine if axle or chassis misalignment affected the results. The test course is shown in Figure 24.

This test was conducted at Blainville.

Instrumentation was used for this test, principally to measure the lateral load at the tractor fifth wheel as the vehicle was driven through the manoeuvre. The axle spacings and loads on the trailers require the tractor to apply a lateral load to turn the combination through the manoeuvre from straight line to full curve. The lateral load measured was considered a measure of the trailer's resistance to turning. The load was measured by the tractor fifth wheel transducer.

The following procedure was used to conduct this test.

Vehicle Preparation

1/ All instrumentation running.
2/ Vehicle loaded.

Test Area Preparation

1/ Set out cones to mark the 29.87 m radius circle and a tangential entry to the circle for each direction. Ensure there are suitable gaps for vehicle entry and exit. Mark the entry point with an extra cone.
2/ Park the cherry picker, with the bucket on the diameter which approximately bisects the entry tangents and is on the opposite side to the entries.

Test Procedure

1/ Approach the entry tangent at low speed with the vehicle straight; park with the tractor front axle on the tangent point and the wheels inside the circle.
2/ Command start tape.
3/ Wait 2 s, then uncage gyro.
4/ Wait 5 s, then proceed at low speed around the circle, with the tractor outer front wheel tracking the circle.
5/ Stop after at least a full circle has been completed, with the off-tracking of the last trailer maximally visible from the cherry picker.
6/ Wait 5 s, then cage the gyro.
7/ Stop the tape.
8/ Measure the distance from the centre of the circle to the inner wheel of each axle.
9/ Measure the distance from the rear axle to the circle.
10/ Shoot video from the cherry picker and other vantage points of interest.

11/ Take still photographs of the vehicle final position.

5.3.2/ Right-Hand Turn

The 90° right-hand turn is probably the most demanding turning manoeuvre for large trucks. In urban areas, or where there are low truck volumes, a small curve radius may be found. When a long truck comes to such an intersection, where the truck is too large to make the turn with a simple steady steer input by the driver, there are two strategies available to create more space for the turn. Either the driver can move to the left of the entry lane to increase the radius, or he can move ahead and intrude into lanes beside the exit lane in the roadway into which the turn is being made. In either case, the driver is using the space of other vehicles, which increases the hazard of the turn. In the first case, it is possible that the driver of a small vehicle also intending to turn right could misunderstand the truck driver's intention in the initial move to the left and become trapped to the right of the truck as it started to turn to the right. This strategy is, therefore, considered undesirable. The second strategy also uses the space of other vehicles, but at least the presence and intention of the truck are clear throughout, and the truck driver would not normally enter that space if oncoming vehicles were too close.

Vehicle trajectory in a right-hand turn was evaluated using a 15 m curb radius, with entry and exit lane widths of 3.66 m, as shown in Figure 25. This has been used in highway geometric design standards for many years for turns from a two-lane two-way road into a four-lane two-way road, where the vehicle may exit in the left-hand lane rather than the right-hand lane. The drivers task is to approach the turn in the entry lane and make the "best" turn possible to exit ultimately in the curb lane. Definition of the "best" turn was left to the judgement of the driver, who repeated turns until satisfied that no further improvement could be made. The swept path of the tractor left front wheel, and rear trailer right rear wheel, were marked with traffic cones on the rays shown in Figure 26. When the "best" turn was achieved, the positions of the cones were measured, and hence, the turn swept path was recorded.

This test was conducted at Centralia. The MTC International tractor was used as the power unit for all vehicles, and the trailers were empty. No instrumentation was used on this test.

The following procedure was used to conduct this test.

Vehicle Preparation

1/ Vehicle empty

Test Area Preparation

1/ Survey in the turn and measurement rays and mark them on the ground with spray paint.
2/ Set out the cones to mark the curb. Mark a start point at point 4 in Figure 25.
3/ Provide a marker cone near each measurement point.
4/ Park the cherry picker adjacent to the exit lane, with the bucket over the exit lane stripe.

Test Procedure

1/ Approach the test area with the vehicle straight; park with the front axle of the tractor at the start point.
2/ When all are ready, make a right-hand turn to exit ultimately in the exit lane. Do not move to the left out of the entry lane. Make the "best" turn possible without running over the "curb."
3/ Place a cone beside the left front wheel and the right rear wheel as each passes over a measurement ray.
4/ Shoot video from the cherry picker.
5/ Take still photographs.
6/ When the "best" turn has been achieved, measure the radii of inner and outer swept path cones from the centre of the curb circle.

5.3.3/ Channelized Right Turn

Vehicle trajectory in a channelized right-hand turn was evaluated using a 25 m curb radius with a channel width of 5.5 m. Entry and exit lane widths were 3.66 m, and deceleration and acceleration taper lengths were 75 and 50 m, respectively. The overall course, with island geometry, is shown in Figure 26. This is a typical highway geometric design standard for use in urban areas, where property presents a problem and speeds are low. The taper lengths assume entry and exit roadway speed limits of 60 km/h. The turn might be superelevated and would have an advisory speed limit of 25 or 30 km/h.

This test was conducted at Centralia, with the MTC International used as the power unit for all vehicles and the test trailers empty. No instrumentation was used for this test.

The following procedure was used to conduct this test.

Vehicle Preparation

1/ Vehicle empty

Test Area Preparation

1/ Survey in the turn, island, and measurement rays; mark them on the ground with spray paint.
2/ Set out the cones to mark the curb, island, and exit lane. Mark a start point with an extra cone at point A of the course, shown in Figure 26.
3/ Provide a marker cone near each measurement point.
4/ Park the cherry picker with a view down the channel towards the rear of the vehicle.

Test Procedure

1/ Approach the test area with the vehicle straight; park with the tractor front axle at the start point.
2/ When all are ready, drive at low speed so that the tractor left front wheel passes as close as possible to point B on the island bull nose. Follow the island curb as close as possible to point C in Figure 26, then proceed into the exit lane.
3/ Place a cone beside the innermost right wheel of the vehicle as it passes near each measurement ray.
4/ Shoot video from the cherry picker.
5/ Take still photographs.
6/ Measure the clearance from the curb to the measurement cones.

This procedure results in measurement of the transient offtracking of the vehicle during passage through the channel, with the tractor following the most favourable line. In practice, there would be a gutter, perhaps 0.30 m (1 ft) wide on the left-hand side, which the driver would not normally use, and the turn might well be made at some speed when the lateral acceleration would tend to reduce the offtracking. Of course, in a congested traffic situation the turn could also be taken at a very low speed.

5.3.4/ Air Brake System

Balanced braking of a combination vehicle requires that the brake systems of all vehicle units be compatible so that pneumatic balance and torque balance can be achieved at each axle. In addition, short brake application and release times provide a brake system responsive to the driver's needs and reduce stopping distance and fuel consumption. Pneumatic

balance and brake timing are both determined by the details for the air brake system, valves, and plumbing. Torque balance is determined by the foundation brake characteristics and axle loads and is a much more complex subject. A comprehensive treatment of the braking characteristics of combination vehicles was beyond the scope of the study. The issues of air brake system compatibility, however, are much more straightforward and could be illustrated by two tests.

1/ The first test follows the style of SAE Standard J982a for timing of the air brake system of a single vehicle unit. The test was, however, applied to the entire vehicle as an operational combination. The test uses a maximum rate brake application, with a regulated air supply at 689 kPa (100 psi), and the time for the air pressure at each axle to reach 414 kPa (60 psi) is determined. The pressures at each axle are also found. Pressure differentials can cause differences in torque between axles, affecting the overall brake balance. Brake release times, which affect the drag on combination vehicles, were also determined. This test is very aggressive, as the high pressure gradients might, for instance, overcome "sticky" valves that would take a significant pressure differential to crack. This test represents the rare emergency brake situation where maximum performance is demanded.

2/ The second test was a service brake application, with treadle valve travel limited to provide about 118 kPa (20 psi) with a 689 kPa (100 psi) supply and a normal rate brake application. The timing and pressure differentials in this test illustrate how the air system behaves in normal use, the usual case.

The following procedure was used to conduct this test.

Vehicle Preparation

1/ Install a pressure transducer in the brake chamber or air hose of one axle of the group fed by each relay valve on each trailer and dolly.
2/ Supply tractor with shop air, regulated at 689 kPa (100 psi).
3/ Check brake strokes and adjust as necessary.

SAE J982a Test Procedure

1/ Select steer period generator (steer period generator [SPG], described in Section 5.3.8) to 8 s.
2/ When all is ready, start tape, wait 2 s, then uncage gyro.
3/ Start SPG using the same hand as uncaged the gyro.
4/ When ready light sequence has been completed, apply maximum treadle

valve, braking at maximum rate.
5/ When SPG completes one-half cycle, after 4 s, release treadle valve.
6/ When SPG completes the full cycle, cage the gyro.
7/ Stop the tape.
8/ Repeat three times.

Service Brake Application Test Procedure

1/ Install treadle valve limiting device and adjust such that maximum available travel corresponds to 118 kPa (20 psi) on the dashboard gauge.
2/ Select SPG to 8 s.
3/ When all is ready, start tape, wait 2 s, then uncage gyro.
4/ Start SPG using the same hand as uncaged the gyro.
5/ When ready light sequence has been completed, apply treadle valve, braking at a normal rate to the limit of available travel.
6/ When SPG completes one-half cycle, after 4 s, release treadle valve.
7/ When SPG completes the full cycle, cage the gyro.
8/ Stop the tape.
9/ Repeat three times.

5.3.5/ Straight-Line Braking Demonstration

The action of braking an empty combination vehicle to a halt on a low-friction surface may result in loss of vehicle control if wheels are locked. The physical characteristics of current braking systems make it extremely difficult to conduct rigorous tests and obtain repeatable results that can be generalized to other vehicles. A series of straight-line stops was therefore conducted to demonstrate modes in which vehicles may become unstable.

In this demonstration the vehicle was driven at 47 km/h onto the wet low-friction test area, which had an approximate skid number of 20, and braked to a halt. A series of runs was conducted with increasing brake application pressure until all wheels of an axle group locked. The driver was allowed to steer as necessary to keep the tractor within the traffic lane. The speed was low enough that incipient unstable behaviour was always evident, but it was not so high as to be unnecessarily aggressive.

The primary results of this test were video tapes showing the vehicle's response to the braking input.

This test was conducted at Centralia. The following procedure was used.

Vehicle Preparation

1/ Deactivate tractor front axle brakes.
2/ Check brake strokes and adjust as necessary.
3/ Vehicle empty.
4/ Hook up treadle valve pressure limiter.

Test Area Preparation

1/ Wet the low-friction test area.
2/ Place a cone at a suitable point adjacent to a marked lane on the test area. This cone will mark the brake application point.
3/ Place a marker so that the gyro can be uncaged 90 m before the start cone.
4/ Park the cherry picker close to the approach and place the bucket as high as possible over the lane centreline.

Test Procedure

1/ Approach the test area at 47 km/h governed speed in a straight line.
2/ Start tape at least 2 s before start cone.
3/ Uncage gyro.
4/ Apply brakes with the treadle valve at the start cone, to the limit permitted.
5/ Do not steer unless a potentially hazardous situation is developing; then make a recovery.
6/ When the vehicle has come to a stop, keep brakes on, wait 2 s, then cage the gyro.
7/ Stop the tape.
8/ Shoot video from the cherry picker and other vantage points of interest.
9/ Take still photographs.
10/ Start with a brake pressure of 103 kPa (15 psi).
11/ For each run, increase brake pressure by 34 kPa (5 psi).
12/ Run once only if there is no lateral/directional instability. When instability occurs, repeat the run to see if the mode is consistent. Do not increase brake pressure after this. If the first unstable run is too exciting, make the subsequent runs with a somewhat lower brake pressure. Do not increase brake pressure past the point where all axles are locking; if the vehicle remains in a straight line at this point, so be it.

5.3.6/ Evasive Manoeuvre

This test is representative of an obstacle avoidance manoeuvre on a two-lane, two-way highway, where the sudden appearance of an obstacle necessitates a fast lane change to the left, then return to the original lane to avoid oncoming traffic. The test course was laid out on a wet low-friction surface, using traffic cones as shown in Figure 27. The vehicle was empty. The driver approached the course at constant speed and manoeuvred the vehicle through the gates, while maintaining speed, without loss of control or contact of any of the cones by the vehicle. A sequence of runs was conducted at increasing speeds until the vehicle became unstable by tractor jackknife, trailer swing, or dolly jackknife, or trailer response resulted in an unacceptable slide out of lane, in excess of 1 m. Runs were repeated when responses were found to be inconsistent with the trend established by preceding runs, or when any cone was struck. When a run was made in which the vehicle response was unstable or undesirable, additional runs, varying by no more than 3 km/h, were conducted to bracket the stability boundary.

This test was conducted at Centralia. It was originally proposed as a lane-change manoeuvre, which is described in Section 5.3.8. However, this task proved too easy for the driver to negotiate for most vehicles when the critical gate size for the most demanding vehicle, the 5-axle 48 ft (14.65 m) semi, was used. In the experience of ministry staff, speeds in excess of 63 km/h were unduly hazardous for an empty vehicle equipped with safety cables on the wet low-friction surface. While the test area was provided with a high-friction shoulder, it was considered that the energy and momentum in total loss of control of a double or triple at any higher speed would be unnecessarily hazardous. Experience has shown that while the test driver is able to duplicate such manoeuvres consistently, the mode of loss of control may not be predictable, so speeds had to be limited for reasons of safety. A symmetrical gate arrangement was selected for the evasive manoeuvre, and the gate size was selected as the minimum that could be negotiated by the most critical vehicle at a speed below the 63 km/h safety limit.

The following procedure was used to conduct this test.

Vehicle Preparation

1/ Vehicle empty.

Test Area Preparation

1/ Set cones to mark an evasive manoeuvre, with gates of 22.5 m, and 20 m in the left-hand lane.
2/ Set an automatic gyro uncage white patch 200 m before the gate.
3/ Position the cherry picker on the left side of the approach, with the bucket centred over the left-hand lane.
4/ Wet the low-friction test area.

Test Procedure

1/ Accelerate the vehicle to test speed, to reach test speed with the vehicle straight at the gyro uncage patch.
2/ Start tape at least 2 s before the gyro uncage patch.
3/ Make manoeuvre through the marked gates, keeping all wheels of the vehicle inside the marked lanes as far as is possible. Exit straight along the marked exit lane.
4/ If a potentially hazardous situation is developing, make a recovery.
5/ When the run has been completed, cage the gyro before turning to exit the test area.
6/ Stop the tape.
7/ Shoot video from the cherry picker and other vantage points of interest.
8/ Take still photographs.
9/ For the first run, use 47 km/h governed speed, then governed speeds until vehicle responses are considered potentially unstable or undesirable, then as specified.
10/ Make each run twice for consistency, but when test limiting speed is approached, make any runs necessary to establish the stability characteristics and threshold.
11/ Do not exceed 63 km/h because of the hazard of total loss of control of a vehicle equipped with safety cables.

5.3.7/ Sinusoidal Steer

In this manoeuvre, the driver approached an open high-friction test area at constant speed with a loaded vehicle and executed a sinusoidal steer input at the steering wheel. This created a sinusoidal lateral acceleration input at the tractor, which resulted in a sidestep to the left, and a vehicle trajectory similar to the single lane change described in Section 5.3.8. The lane change is constrained within a 3.66 m (12 ft) lane, whereas the sinusoidal steer results in a variable sidestep depending upon the speed and steer amplitude. The steer input was made to achieve a tractor lateral acceleration of about 0.15 g.

This steer input is simply a standard method by which lateral/directional response of the vehicle could be excited. The input was chosen to be large enough to get a reasonable response from the vehicle, but not so large that units of the most responsive vehicles would be sliding or rolling excessively. This steer input permitted the lateral acceleration of each trailer of a combination vehicle to be examined, relative to the tractor lateral acceleration. These acceleration ratios, properly known as rearward amplification of lateral acceleration, are an important inherent dynamic characteristic of combination vehicles. An acceleration ratio no greater than unity means the trailer has a lower acceleration than the tractor, so basically the driver may be considered in control of vehicle response as he is in a position to sense the greatest lateral acceleration in the vehicle. An acceleration ratio greater than unity means a trailer has a higher lateral acceleration than the tractor, and if the ratio and tractor lateral acceleration are high enough, the trailer may slide or roll over even though the driver feels the tractor is still fully under control.

A vehicle that has a higher rearward amplification than another results in a greater vehicle response per unit steer input. This means that it is more sensitive, or less stable, in its lateral/directional dynamic characteristics. This test, then, examines the inherent dynamic stability of the vehicle.

The test was run at speeds of 63, 84, and 94 km/h, which were the actual governed speeds in the gear that came closest to the target speeds of 60, 80, and 100 km/h. Steer periods of 4, 3.5, 3, 2.5, and 2 s were used. A true-tracking, sinusoidal input computer program for the Freightliner, using a 37.5:1 steer ratio, provided the necessary steer amplitudes to generate approximately 0.15 g lateral acceleration at the tractor for each speed and steer period tested. These amplitudes were provided to the driver by means of indicators on the steering wheel.

Since it was considered somewhat difficult for the driver to estimate and perform a steer input of specific period, an electronic device was developed that provided a guide. This steer period generator (SPG), shown in Figure 28, consists of two boxes. The first box contains the electronics and controls. The driver selected the desired steer period by means of a switch, in increments of 0.5 s. Immediately after the gyro was uncaged, the driver would start the SPG and follow the light sequence given by the display box. The centre prompting lights came on at 1 s intervals to count down to the start of the steer. The horizontal light cycle would

come on in sequence from the centre to the left, go off in the reverse sequence, then come on in sequence from the centre to the right, and go off in the reverse sequence. One complete period for the horizontal cycle lights was the selected steer period. The driver merely needed to follow these lights, reaching full steer to the left and right as the far left and far right lights illuminated, respectively, to achieve the correct steer period. This device worked well, as the driver was able to conduct the test in an orderly manner without the need for wasted runs to achieve a particular period by a series of trials. The device would also operate in a free-running, repeated-period mode. The driver sometimes used this mode, or the single-period mode, between two runs to get the "rhythm" of the next run.

This test was conducted at Blainville. The following procedure was used.

Vehicle Preparation

1/ Vehicle loaded.

Test Area Preparation

1/ Set cones to mark an approach to the test area.
2/ Set an automatic gyro uncage white patch 200 m before the start of the manoeuvre.
3/ Park the cherry picker on the left side of the approach, with the bucket adjacent to the approach lane.

Test Procedure

1/ Mark steering wheel at the specified amplitude.
2/ Accelerate the vehicle to test speed, to reach test speed with the vehicle straight at the gyro uncage patch. Use governed speeds of 63, 84, and 94 km/h.
3/ Start tape at least 2 s before the gyro uncage patch.
4/ Start the SPG at a suitable point, about 4 to 5 s after gyro uncage.
5/ Make a sinusoidal steer to the left. Do not worry about the vehicle heading once the steer input has been completed, but make sure that the exit is straight and is held long enough for vehicle responses to be completed before caging the gyro. Steer amplitudes should be kept such that the tractor lateral acceleration is in the range 0.1 to 0.2 g and the rear trailer is not sliding laterally.
6/ When the run has been completed, cage the gyro before turning to re-enter the high-speed track.
7/ Stop the tape.

8/ Shoot video from the cherry picker and other vantage point of interest, for typical runs,
9/ Take still colour photographs.

5.3.8/ Lane Change

The lane change on a standard highway requires a steer input by the driver that is similar to the sinusoidal steer. The amplitude of the steer input must be such that a sidestep of 3.66 m (12 ft) is achieved if the vehicle starts in the centre of one lane and moves over to the centre of an adjacent lane. This test is representative of an obstacle avoidance manoeuvre on a multilane highway, where the sudden appearance of an obstacle necessitates a fast lane change to the left.

The test course was laid out on a high-friction surface, as shown in Figure 29. The 30 m (98 ft) gate was selected so that speeds at the limits of stability for all vehicles would be in the range of 70 to 90 km/h. The vehicle was loaded, and the driver approached the course at constant speed. The driver's task was to manoeuvre the vehicle through the gates while maintaining speed, without loss of control or contact of any of the cones by the vehicle. A sequence of runs was conducted at increasing speeds until the vehicle became unstable by rollover or trailer swing, or trailer response resulted in an unacceptable swing out of lane, defined here as in excess of 1 m. The sinusoidal steer test described in Section 5.3.7 is a subcritical test, designed to display the dynamic characteristics of a vehicle. This test takes basically the same manoeuvre as the sinusoidal steer, to determine the limits of stability of the vehicle and demonstrate the mode by which it becomes unstable. The cone layout simply imposes a task on the driver and ensures repeatable results.

Runs were repeated when responses were found to be inconsistent with the trend established by preceding runs or when any cone was struck. When a run was made in which the response was unstable or undesirable, additional runs, varying by no more than 3 km/h, were conducted to bracket the stability boundary. The test was terminated if the vehicle reached 100 km/h, a typical maximum legal speed in provinces of Canada, and was still able to make the manoeuvre successfully.

This test was conducted at Blainville. The following procedure was used.

Vehicle Preparation

1/ Vehicle loaded.

Test Area Preparation

1/ Set cones to mark a lane change to the left, with a gate of 30 m.
2/ Set an automatic gyro uncage white patch 200 m before the gate.
3/ Position the cherry picker on the left side of the approach, with the bucket centred over the left-hand lane.

Test Procedure

1/ Accelerate the vehicle to test speed, to reach test speed with the vehicle straight at the gyro uncage patch.
2/ Start tape at least 2 s before the gyro uncage patch.
3/ Make a lane change to the left through the marked gate, keeping all wheels of the vehicle inside the marked lanes as far as is possible. Exit straight along the marked exit lane.
4/ If a potentially hazardous situation is developing, make a recovery.
5/ When the run has been completed, cage the gyro before turning to re-enter the high-speed track.
6/ Stop the tape.
7/ Shoot video from the cherry picker and other vantage points of interest.
8/ Take still colour photographs.
9/ For the first run, use 47 km/h, then governed speeds until vehicle responses are considered potentially unstable or undesirable, then as specified.
10/ Make each run twice for consistency, but when test limiting speed is approached, make any runs necessary to establish the stability characteristics and threshold.

5.3.9/ Normal Straight-Line Driving

The trailers of combination vehicles tend to sway a small amount in straight-line driving because of road roughness and the normal small steer corrections by the driver. This sway is related to vehicle configuration in the same way as rearward amplification of lateral acceleration. Some jurisdictions may impose a 75 mm (3 in) sway amplitude limit on trailers. The limit, however, is non-specific because it is not related to the input to the vehicle. It is also difficult, if not impossible, to enforce because the sway cannot be measured; it can only be subjectively estimated.

This test was conducted at Blainville. The following procedure was used.

Vehicle Preparation
1/ Vehicle loaded

Test Area Preparation
1/ Use a straight portion of the high-speed track.

Test Procedure
1/ Drive at a steady speed of 100 km/h.
2/ Start tape at least 2 s before gyro is uncaged.
3/ Uncage the gyro manually when the vehicle is travelling in a straight line down the track.
4/ Drive normally as if cruising in a lane on a highway.
5/ Cage the gyro before leaving the straight track.
6/ Shoot video from a chase car following the vehicle.
7/ Make at least two runs along the full length of the straight track section.

5.3.10/ Steady Circular Turn

A loaded vehicle can roll over in a steady circular turn if its speed is high enough. Such a situation typically occurs for vehicles with a high centre of gravity when driven at excessive speed on a freeway ramp. There is often dynamics involved in such accidents, due to braking, steering, or both, as the driver attempts to negotiate the ramp. However, the essential mechanism involved is that of rollover in a steady circular turn, which is an important inherent stability characteristic of a vehicle. This test examined that characteristic.

Static rollover characteristics of all vehicles tested, except the triples, were examined in a parallel part of the study conducted by Centre de Recherche Industrielle du Quebec (CRIQ), using a tilt table built for this purpose. Vehicles were provided to CRIQ staff, loaded as for this test, but with outrigger outer sections removed so that the vehicle could fit on the tilt table. The vehicle was driven onto the table, with load cells located strategically beneath wheel groups on each side of the vehicle. The axles and trailer bed were suitably restrained, and tilt meters were attached. The table was then continuously tilted until enough axles on the high side of the vehicle had lifted for the vehicle to be deemed to have reached the rollover point. Results of the tilt tests have been presented separately by CRIQ [12].

The tilt test provides static roll characteristics of a vehicle. It may be presumed these would be related to the rollover characteristics arising from a steady circular turn.

The steady circular turn course was laid out using traffic cones on a dry high-friction surface, as shown in Figure 30. The circle had a radius of 50 m (164 ft) and was approached along a tangent leading to a 100 m (328 ft) long spiral. The vehicle was loaded, and the driver followed the approach at a specified constant speed, entered the circular turn as smoothly as possible, and tracked on the outside for as long as possible. A sequence of runs was conducted at increasing speeds until the vehicle became unstable by rollover or trailer swing, or the driver could not maintain either the desired trajectory or the speed. Sufficient runs were made to map out the vehicle roll response as a function of speed.

The outriggers were set such that the vehicle wheels on the inside of the turn would lift by 0.15 to 0.20 m (6 to 8 in) at outrigger touchdown, which corresponds to about 6 to 7° of body roll. The outrigger clearance settings varied between vehicle units and vehicles, because of attachment and adjustment limitations. More important, however, were the differences in suspension and torsional stiffnesses between vehicles. A-trains could clearly roll over the rear trailer, but in others, outrigger touchdown may occur on some trailer but the entire vehicle can still be short of the rollover point. Outrigger touchdown, therefore, simply denoted a point beyond which further testing was impractical. When wheel lift and outrigger touchdown occur for some vehicles, the vehicle speed often drops off significantly, and it becomes difficult for the driver to maintain the circular turn. Therefore, steady-state data for this condition cannot be obtained. There would not necessarily be any relationship between outrigger touchdown points for each vehicle. It was, therefore, considered more useful to map the vehicle characteristics as a function of speed rather than simply establishing an arbitrary outrigger touchdown point.

This test was conducted within the vehicle dynamics area at Blainville. The following procedure was used.

Vehicle Preparation

1/ Vehicle loaded.

Test Area Preparation

1/ Set cones to mark a circle of 50 m (164 ft) radius, with a suitable

tangent and spiral entry.

2/ Set an automatic gyro uncage white patch a suitable distance on the tangent before the entry to the spiral.

3/ Park the cherry picker outside the circle about on a tangent from the point where the vehicle will roll over, with a view of the rear and outside of the vehicle.

Test Procedure

1/ Approach the test area along the entrance tangent at the specified speed, with the vehicle straight at the gyro uncage patch.

2/ Start tape at least 2 s before the gyro uncage patch.

3/ Proceed around the spiral and circle, at constant speed, with the left front wheel tracking the curve. Hold the circle for at least 90° or until outrigger touchdown occurs.

4/ If a potentially hazardous situation develops, make a suitable recovery.

5/ When the run has been completed, cage the gyro.

6/ Stop the tape.

7/ Shoot video from the cherry picker and other vantage points of interest.

8/ Take still colour photographs.

9/ For the first run use 35 km/h governed speed, then governed speeds, then increase speed incrementally according to vehicle response.

10/ Make each run twice for consistency. As the rollover speed is approached, only runs necessary to establish the rollover threshold need be done.

5.4/ Data Capture

The data acquisition system consisted of a signal conditioning and pulse-amplitude modulated (PAM) multiplex system mounted in the sleeper portion of the MTC Freightliner, and others mounted in instrumentation boxes on the trailers. The systems were configured to provide the necessary transducer excitation and signal conditioning to permit multiplex transmission and recording of up to 40 individual signals. Electrical signals produced by the transducers were conditioned by individual plug-in-type adapter cards within the multiplex unit, as shown in Figure 31. A maximum input from each transducer was selected, and the conditioner parameters were adjusted to provide an output signal of 2.0 V for the chosen full-scale input. The conditioned output signals were transmitted as a PAM data stream from each multiplex system to a control unit in the tractor, which synchronized and merged the three PAM data streams. A 12-bit

analog-to-digital converter in the control unit digitized the 36 data channels at a rate of 100 samples/s for each channel and produced a pulse-code modulated (PCM) data stream in a standard IRIG format. The control unit added two synchronization words containing a unique bit pattern, and two digital data words, to the 36 data words to produce a data frame of 40 twelve-bit words. One digital word was used to provide system and vehicle status, and the other was used for optical sensor status. The PCM data stream was broadcast by radio telemetry from the tractor to a ground station, using a radio frequency licensed to the ministry for use at both Centralia and Blainville.

The ground station was located in the MTC building at Centralia. The ground station equipment was installed in a former transit bus, which served as the ground station during tests at Blainville (Figures 32 and 33).

The ground station received the PCM data stream and recorded it as received on one track of a Honeywell 5600C instrumentation tape recorder. IRIG B time code generated by a Datum 9300 time clock was recorded on a second track of the recorder so that the location of a particular run could be found easily if data playback was required. This recording was for archival and backup purposes.

The PCM data stream was processed by the decommutator, which formatted it into a bit-parallel, word-serial, input stream for an Hewlett-Packard HP-1000 A700 computer in the ground station (Figure 34). The computer read each run in real time and created a raw data file on disk for subsequent processing. The project engineer at the computer graphics terminal had a quick-look display that provided an overview of system status functioning and data quality while the run was in progress.

Before each test session, an electronic calibration of the entire data acquisition system was conducted. Any necessary adjustments were identified and made, and a second calibration was recorded. At the beginning of each test run, the control unit on the tractor was made to step automatically through a calibration sequence, either by automatic command from the optical sensor or by manual command from the driver. This was recorded as part of the run data, to permit current system calibrations to be used for each run. The gyros on board the vehicle were uncaged by a trigger signal from a reflective panel placed on the approach and sensed by an optical sensor.

Each run was recorded on colour video tape, from the vantage point of a cherry picker, other vantage points of interest, or both, as shown in Figure 35. Each run was preceded by a shot of the day and run numbers, so that it was chronologically identifiable. The audio track of the video system was used to record ambient noise during testing, including incidental radio transmissions.

Still colour photographs and colour slides of the vehicles, equipment, and activities were also taken. Manual notes and logs of all test conditions and observations were made. A log of all test runs was maintained within the computer.

5.5/ Data Processing

Data processing was conducted concurrent with testing. At the beginning of each day, certain data files and procedures were initialized within the HP-1000 computer system. Data from each run were captured in real time by the HP-1000, and the raw data were stored in a file on disk, as described previously. The raw data were reviewed by the project engineer on a graphics display, to determine whether all critical data channels were functioning correctly and whether the run appeared to meet the specified test conditions. The raw data file was then read, electronic calibrations were applied, each channel was converted to engineering units, and a calibrated data file was created. Quantities of interest were derived, and those critical to the test were displayed to the project engineer, who used them to make recommendations for the next run by radio to the test director on the track. After each test session, all raw data files; other files created in support of the data processing process, such as the run log file and a summary file of derived quantities; and all data input files which controlled the data processing were archived to a tape. The archived tape was indexed and complete, so that the processing of any particular run could be reconstructed.

Upon completion of the test program, all data processing procedures were exhaustively reviewed, and any necessary enhancements were implemented and validated. All supporting data files were also reviewed. Every run was carefully reviewed, and those runs that did not meet the particular test objective, or were otherwise so flawed that the data could not be processed, were discarded.

Data processing proceeded in four phases:
1/ raw data correction

2/ calibration
3/ treatment
4/ extraction of results

The first phase, raw data correction, simply corrected any data frames in which telemetry dropout occurred. These frames usually showed up as spikes on most data channels, as shown in Figure 36. Telemetry dropout occurred intermittently throughout the test program for no obvious reason. When it occurred, the decommutator was unable to find the 24-bit synchronization pattern in the PCM data stream and ceased transmission of data frames to the computer. This resulted in partial loss of the frame during which dropout occurred, total loss of an unknown number of complete frames, and capture of one or two scrambled frames while the computer data acquisition was regaining synchronization with the decommutator. Examination of the PCM data stream by oscilloscope showed that dropouts were usually momentary, so in most cases no more than one or two frames were actually lost. However, since the data acquisition procedure was taking its timing from the decommutator, not an independent source, the number of frames actually lost was never known. Runs were rejected in which there occurred frequent dropouts or dropouts during the steer input or vehicle response. It was only necessary to correct raw data when a dropout occurred in the approach to the manoeuvre or after vehicle response was complete. It was judged that loss of a few frames was not critical in these regions. The correction procedure for each dropout was simply a linear interpolation for each channel of all invalid frames between the last valid frame before the dropout and the first valid frame after the dropout.

Calibration proceeded in two phases. As previously mentioned, the on-board data acquisition system was commanded through an electronic calibration sequence at the beginning of data acquisition for each run. The calibration sequence consisted of approximately 0.5 s of each of negative full scale, zero, and positive full scale, as shown in Figure 37. The calibration was achieved by switching a precisely controlled voltage to all channels of the signal conditioners. A voltage calibration for each step of the calibration sequence was computed as the moving average value of lowest root mean square. If the root mean square exceeded 5% of full scale, the calibration was rejected. The calibrations usually differed from the nominal values by less than 1% of full scale. Any deviation of more than 2.5% was flagged as a potential error, requiring examination of the data for correctness and, perhaps, the instrument for function. Channels using strain gauge signal conditioner cards, where the data are

superimposed upon the calibration and even a small drift from zero could result in a false error flag, were an exception. If nominal full scale is V volts, and the measured voltage is C volts, then a linear calibration of k units full scale must be applied to the actual data as kV/C. This is done by modifying the value used for conversion to engineering units, the second phase of calibration. The actual details of this take account of both offsets and slopes for electronic and engineering units calibration and are a little more involved than the simplified explanation given here.

The term "treatment" is used for the sequence of operations whereby the now calibrated data are processed so that specific quantities of interest for a particular test can be derived. Some of these operations are applied to the output of a particular instrument, while others may be used rather generally on various types of data. The following treatments were used in data processing:

1/ transformation of speeds of all free-rolling wheels to the speed of the tractor right front wheel;
2/ transformation of the sawtooth wave distance measurement to actual distance;
3/ correction of trailer lateral accelerations for the gravitational effect of roll angle;
4/ integration of yaw and roll rates to yaw and roll angles, respectively;
5/ detrending of data;
6/ filtering of data.

The first four of these are straightforward; the other two need some explanation. Detrending removed trends in transducer responses. It was used in two ways. In most tests, the vehicle was assumed to be in a nominal zero condition initially, and the response of interest was relative to that condition. However, the actual measurements gave an initial mean value that was not zero. While these deviations were usually only a few percent of full scale, they could have a marked effect on results if not properly dealt with. The procedure used was simply to compute an average value for each nominally initially zero channel over a short period at the start of a run. This value was then subtracted from each data point for a channel, thus moving the initial average to zero. The second type of detrending was used for channels which should have returned to zero after a response to the input was complete but did not due to instrument drift during the run. Examples of these are the roll and yaw angles measured by the various gyros. These channels were

detrended by fitting a straight line by the least squares method to the nominally zero data segments at the beginning and end of the run, then subtracting this linear trend from the actual data. The detrending process is illustrated in Figure 38, for tractor yaw angle.

Filtering was used to remove unwanted frequency content from data. In most cases the responses of interest were related to the frequency content of the steer input, which was below 1 Hz. However, many channels had superimposed vibration responses of the vehicle, such as axle hop, vibration due to roadway irregularity, and a particular vibration apparently associated with the tractor drive axle tires. An optimal linear finite impulse response low-pass filter [13] was designed having a cutoff frequency of 1 Hz, a stop band 50 dB down at 4 Hz, and a 0.03 dB ripple in the passband. This filter had 53 weights, and maximum deviations of 0.00441 and 0.00403 in the passband and stop band, respectively. This filter was applied to all data channels except wheel speed, distance, and brake chamber pressures.

The final phase of data processing was extraction of results. The method used depended entirely on the test being processed. Details of the methods are presented in the following sections. Typical results extracted were speed, peak or average responses, response gains, steer period, and so on. A summary file was created for each test, and the results for each run were stored in this file. At the completion of the test, the data in the summary file could be cross-plotted. For instance, rearward amplification gain for a series of steer period inputs could be plotted against the speed, or some peak response could be cross-plotted against speed or lateral acceleration. This provided an easy, semi-automatic way to view trends across all the runs of a particular test.

5.5.1/ Offtracking

The measurements recorded manually during the test were tabulated. Average values from the two turns were compared with a geometric estimate of steady-state offtracking made by the WHI formula [14].

5.5.2/ Right-Hand Turn

The measurements recorded manually during the test were simply tabulated and plotted. Intrusion of the vehicle into the exit lane was estimated from the plot.

5.5.3/ Channelized Right Turn

The measurements recorded manually during the test were simply tabulated and plotted.

5.5.4/ Air Brake System

This procedure was used to derive the characteristics of the pneumatic system that affect balanced braking of a combination vehicle.

All brake pressure signals were detrended so that their initial average pressure was zero. Brake status was monitored using the brake light switch, the condition of which was stored as a single bit in a digital word provided by the PCM control unit in the tractor. The first frame which contained this bit was considered the start of brake application. The time for each brake chamber to reach 414 kPa (60 psi) from the start of brake application was computed. This was in accordance with the procedure of SAE J982a or US Standard FMVSS121. The final steady pressure before release was also computed. This final pressure did not always reach 689 kPa (100 psi) or even 655 kPa (95 psi). Release timing was therefore computed from the instant the treadle valve pressure began to decrease. The release time for each brake chamber was computed as the time for the pressure to reach 34 kPa (5 psi) from the instant of treadle valve release. This differs from the procedure of SAE J982a or FMVSS121, which require the vehicle pneumatic system to be charged to 689 kPa (100 psi) before release. However, those procedures apply to single vehicle units, and the procedure described here was considered adequate to provide insight into the pneumatic characteristics of the combination vehicle.

A typical time history from this test is shown in Figure 39.

Basically, the same procedure was used for the application and steady-state portion of the service brake application test, though in this case the timing was computed to 60% of the peak pressure arising during the test. Release characteristics were not considered during this test.

5.5.5/ Straight-Line Braking

While this demonstration was primarily qualitative, data were captured and processed to determine vehicle responses in straight-line braking.

All input channels were properly detrended, and all channels except the brake pressures were filtered.

The start of brake application was found as described previously and was used as the initiation of the manoeuvre. The initial average speed was found over the 1 s period before the instant of brake application. The end of the manoeuvre was defined either as the point where the vehicle's velocity became zero or the instant when the brakes were finally released if the driver drove out without coming to a complete stop. The stopping distance and time to stop (or deceleration distance and time, if it was not a complete stop), average deceleration, peak and average brake application pressures, peak steer angle, vehicle unit articulation angles, heading angles, and lateral accelerations were all computed over the period of the brake application.

5.5.6/ Evasive Manoeuvre

This procedure was used to compute vehicle responses to an evasive manoeuvre and derive quantities of interest for summary of results of a series of runs.

All input channels were properly detrended and filtered.

The start of the steer input was found at the first point where the steer input exceeded a specified tolerance for five consecutive scans. The tolerance was chosen so that it was always greater than the small steer corrections made on approach, but was not so large that it approached the steer amplitude.

The initial speed was determined from the average speed for the 1 s of data immediately preceding the start of the steer input.

Peak values of steer input and specified responses were found from the start of the steer input to the end of the data, either end of record or end of a specified base segment. Specified responses were tractor yaw rate, lateral accelerations, articulation angles and vehicle unit heading angles, and all other channels of interest. Peak values were largest positive and least negative, and the corresponding times at which these peaks occurred were also found. Care was taken to ensure that the data segment scanned included only the data of interest: for instance, if it included a sharp turn for vehicle recovery at the end of the run, this could result in misleading peak values in excess of those in the actual

region of interest.

The three lateral acceleration response peaks due to the steer input and the two heading peaks and any overshoot were determined by a search procedure. The time at which the steer input first crossed zero was used as a time base. The tractor lateral acceleration was then searched from one-quarter the steer period before this time to one-half the steer period after its zero crossing. This was used as a new base, and the peak responses to each half-wave of the steer input were found by searching backward and forward from this for each trailer successively rearward.

5.5.7/ Sinusoidal Steer

This procedure was used to compute vehicle responses to an evasive manoeuvre and derive quantities of interest for summary of results of a series of runs.

All input channels were properly detrended and filtered.

The start of the steer input was found at the first point where the steer input exceeded a specified tolerance for five consecutive scans. The tolerance was judiciously chosen so that it was always greater than the small steer corrections made on approach, but was not so large that it approached the steer amplitude.

The initial speed was determined from the average speed for the 1 s of data immediately preceding the start of the steer input.

The steer period was estimated by computing the steer angle autocorrelation for a specified number of lags, starting at the start point found. The autocorrelations were computed over the entire rest of the record. It is known that the autocorrelation of a sine wave is a cosine function of the same frequency. A single cycle sine wave results in a damped cosine. The autocorrelation crosses zero at a time which is one-quarter the period of the input sine wave. This point was found, and the period was assumed to be four times the lag which resulted in the autocorrelation crossing zero. This period was reduced by an empirical factor of 0.95, as this appeared to give a better fit to the measured data. A synthetic true sine wave of the period determined was created, centred to cross zero at the point the measured steer crossed zero. The amplitude of the synthetic steer was computed as

SUM(Y(I)*S(I))/SUM(S(I)*S(I)) for I = 1, N

where Y(I) is the measured steer input
S(I) is the synthetic steer

This seemed to give a better overall fit than either using one of the measured peaks or an average of the two. The steer balance was computed as the integral of the measured steer angle over the period of the synthetic steer. This should be close to zero for a well-balanced sinusoidal steer. The fit procedure just described seemed to work reasonably for a well-balanced steer input but was not so good if the two half-waves were unbalanced in either amplitude or duration or if there was a third or subsequent small correction half-wave following the main steer input. Typical fitted sine waves are shown in Figure 40, for well-balanced and unbalanced sinusoidal steer inputs.

The tractor yaw rate response lag was computed as that lag time for which the cross-correlation of steer input and yaw rate was greatest. The correlation was the normalized cross-correlation for this lag.

Peak values of steer input and specified responses were found from the start of the steer input to the end of the data, either end of record or end of a specified base segment. Specified responses were tractor yaw rate, the gains found in lateral accelerations and roll angles, and all other channels of interest. Peak values were largest positive and least negative, and the correspoding times at which these peaks occurred were also found. Care was taken to ensure that the data segment scanned included only the data of interest: for instance, if it included a sharp turn for vehicle recovery at the end of the run, this could result in misleading peak values in excess of those in the actual region.

The two peaks in lateral acceleration and roll response, and the single heading response peak, were determined by a search procedure. This started from the tractor and proceeded rearward to the last trailer. The time at which the steer input crossed zero was used as a time base. The tractor lateral acceleration was then searched from one-quarter the steer period before this time to one-half the steer period after for its zero crossing. This was used as a new base, and the peak responses to each half-wave of the steer input were found by searching backward and forward from this for each trailer successively rearward. Lateral acceleration gains were then computed for all trailers. The gain was computed by dividing the peak-to-peak trailer response by the peak-to-peak response of the tractor, as shown in Figure 41. It gave the same result as the

conventional method of dividing by the peak tractor response for the case of a well-balanced steer but resulted in less data scatter for cases when the steer input was not well balanced, which was often the case for the small steer input required for responsive multi-trailer combinations.

Note that in cases of trailer swing or rollover, the rear trailer overshot the second half-wave and could have a third half-wave, which was sometimes of substantially greater amplitude than the two half-waves thatare the forced response to the steer input. This half-wave was not considered in this procedure, but it indentified by the peak response procedure previously described.

5.5.8/ Lane Change

This procedure was used to compute vehicle responses to a lane-change manoeuvre and derive quantities of interest for summary of results over a series of runs.

It was exactly the same as that used to determine the start of the steer input, the initial speed, steer period, tractor yaw rate response, and peak responses and gains, described in Section 5.5.7. However, the procedure was extended to select three response peaks, rather than the two of the sinusoidal steer. The first two peaks were the same for both manoeuvres, simply due to the steer input required to make the lane change. At low speeds the vehicle was well damped and there was no third peak. However, as the limiting speed was approached there was a third peak, the overshoot due to reduction in stability of the vehicle. A small overshoot may be seen in the trailer 2 lateral acceleration response at a time of about 7 s in Figure 41. Note that sometimes the driver completed the steer input, which was essentially sinusoidal, but overshot or deliberately corrected to exit straight along the marked lane. This additional steer, present to a small extent in the steer angle input of Figure 41, also can result in the overshoot. No distinction was made between the two possible causes of the response overshoot. In addition, the two response peaks of each vehicle unit's heading angle were found using the same technique. The basic tractor heading angle has a single peak, as shown in Figure 38, to which may be added an overshoot as the limit of stability is approached, particularly for trailers swinging out of lane.

5.5.9/ Normal Straight-Line Driving

Each run was detrended so that the steer articulation angles had an initial average value of zero. These data were also filtered. The sway at the rear of each trailer, relative to the tractor fifth wheel, was computed based on the articulation angles, kingpin to hitch distances, and kingpin to rear distances, for each trailer. The range and root-mean-square (RMS) steer input, and sway and lateral acceleration of each trailer, were computed for each run. Vehicles were then compared on the basis of the ratio of RMS sway to RMS steer input, in units of mm/degree; the ratio of RMS lateral acceleration to RMS steer input, in g/degree; and the sway range in mm. These simple ratios were used because much of the data were less than 1% of full scale, which is, in some cases, the level of resolution. A proper frequency domain analysis, therefore, did not appear warranted.

5.5.10/ Steady Circular Turn

This procedure was used to compute vehicle responses to a steady circular turn and derive quantities of interest for summary of results of a series of runs.

All input channels were properly detrended and filtered.

The start of the steer input was found at the first point where the steer input exceeded a specified tolerance for five consecutive scans. The tolerance was judiciously chosen so that it was always greater than the small steer corrections made on approach, but was not so large that it approached the steer amplitude.

The instantaneous radius of curvature was computed based on velocity and yaw rate or lateral acceleration. The high-speed offtracking was also computed, based on an assumed tractor attitude and the articulation angles.

The initial speed was determined from the average speed for the 1 s of data immediately preceding the start of the steer input.

Once the initial speed and start of steer input were known, it was possible to project forward to a region of steady-state response, because the length of the spiral was known. It was found easier to use a region fixed in space for each vehicle unit, rather than a fixed interval of

time, because for the longest vehicles, the triples, the driver could have been starting recovery from the manoeuvre as the rear of the vehicle was reaching steady state. The steady-state segment, therefore, was defined as that location tranversed by the tractor in the 4 s or as long as was available, after the tractor had been on the circular turn for 2 s. Note that there were difficulties with the data. Some vehicles, particularly the B- and C-trains, tended to slow significantly in the circular turn due to the way of turning. Further, when a rollover or trailer swing occurred, the driver effected an immediate recovery, so steady-state data really did not exist for these most interesting cases.

Peak, mean, and RMS values of steer input and specified responses were found over the region of steady-state response. Specified responses weretractor yaw rate, lateral accelerations, roll angles, articulation angles, and all other channels of interest. Peak values were largest positive and least negative, and the corresponding times at which these peaks occurred were also found. Care was taken to ensure that the data segment scanned included only the data of interest: for instance, if it included a sharp turn for vehicle recovery at the end of the run, this could result in misleading results.

6/ PERFORMANCE MEASURES

The vehicle configurations are evaluated using various performance measures. Some of the measures are addressed by simulation or analysis of various kinds, others by test, and some by both.

The following performance measures provide the basis of what will be considered from tests:

1/ steady-state roll characteristics, derived from circular turn manoeuvres for loaded vehicles;
2/ dynamic roll threshold, derived from lane-change manoeuvres for loaded vehicles;
3/ roll mode characteristics, from the manoeuvres of 1 and 2;
4/ rearward amplification of lateral acceleration, from sinusoidal steer and lane-change manoeuvres;
5/ lateral/directional stability (jackknife and trailer swing), derived from evasive manoeuvres with an empty vehicle on a low-friction surface;
6/ straight-line trailer sway for loaded vehicles;
7/ vehicle stability characteristics in straight-line emergency braking, empty on a low-friction surface;
8/ high-speed offtracking, derived from the steady circular turn;
9/ lateral loads at the tractor fifth wheel, derived from the steady circular turn and lane-change manoeuvres;
10/ yaw response gains and lag times;
11/ vehicle speed at lateral/directional and rollover stability thresholds;
12/ steady-state offtracking;
13/ swept paths in typical right-hand turns;
14/ air brake system application, release timing, and pneumatic balance.

These performance measures were computed from the measured data by the HP-1000 computer, as described previously. The values were stored in a file indexed by run, making it possible to display vehicle response characteristics against input parameters, for purposes of test management and data analysis.

7/ COMPUTER SIMULATION

The University of Michigan Transportation Research Institute (UMTRI) yaw/roll model [15] was installed on the HP-1000 computer used in the ground station for data capture and processing. The program was extended to simulate a triple trailer combination and was updated to include an improved B-dolly model developed by UMTRI, so that all vehicles tested could be simulated with the same program.

The properties of vehicle unit suspensions were available from parametric measurements made by UMTRI, as were tire properties [16]. The geometric properties of vehicles were measured, and mass properties were determined by a process of weighing and calculation. By this means, data sets were prepared that were representative of the vehicles as they were actually tested.

The program was also modified to read the steer input measured during a test run, and the initial conditions for some other model degrees of freedom, from the test data. It then integrated the equations of motion, computed responses of interest at the measurement locations on the test vehicle, and stored those responses in a data file having the same format as that containing the responses measured in the test. The test and simulation results could, then, be directly compared.

This test program consisted of standardized tests of nine vehicles of different configurations. It provided an opportunity to compare computer simulation with test data over a wide range of cases. The objective was to demonstrate that computer simulation could represent a vehicle's response in a specific manoeuvre, and the trend in response characteristics over a range of manoeuvres. The program data were set up to be as representative as possible of the actual vehicle tested, using generic data where directly measured data were not available. This work was not a validation of the computer model.

Computer simulation was conducted for all vehicles for the following tests:

1/ sinusoidal steer
2/ lane change with loaded vehicle on high-friction surface
3/ steady circular turn

A detailed summary of this work is presented elsewhere [17].

8/ CONCLUSIONS

This report has presented procedural details for preparing and conducting tests and processing and analysing data, for test of baseline and additional vehicles for the CCMTA/RTAC Vehicle Weights and Dimensions Study. The report presents this information as a common reference for the detailed test reports for the particular vehicles.

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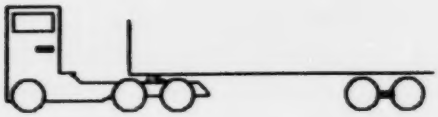
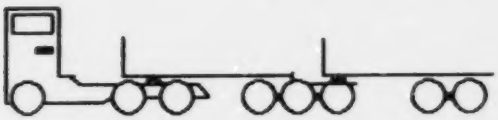
[16] Interim data package on parameter measurements conducted for the Vehicle Weights and Dimensions Study by UMTRI.

[17] Lam, C.P., and Billing, J.R., "Comparison of Simulation and Test of Baseline and Tractor-Trailer Vehicles," Ontario Ministry of Transportation and Communications, Transortation Technology and Energy Branch, Report CV-86-11, June 1986.

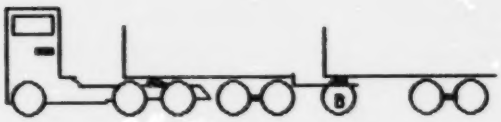


5-AXLE 45 FT SEMI

A-TRAIN DOUBLE



B-TRAIN DOUBLE



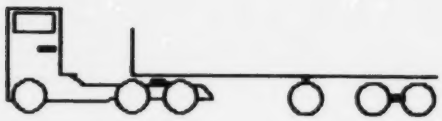
C-TRAIN DOUBLE

A-TRAIN TRIPLE

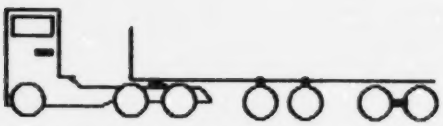
C-TRAIN TRIPLE

Figure 1/ Baseline Vehicle Configurations

5-AXLE 48 FT SEMI



6-AXLE 48 FT SEMI



7-AXLE 48 FT SEMI

Figure 2/ Additional Vehicle Configurations

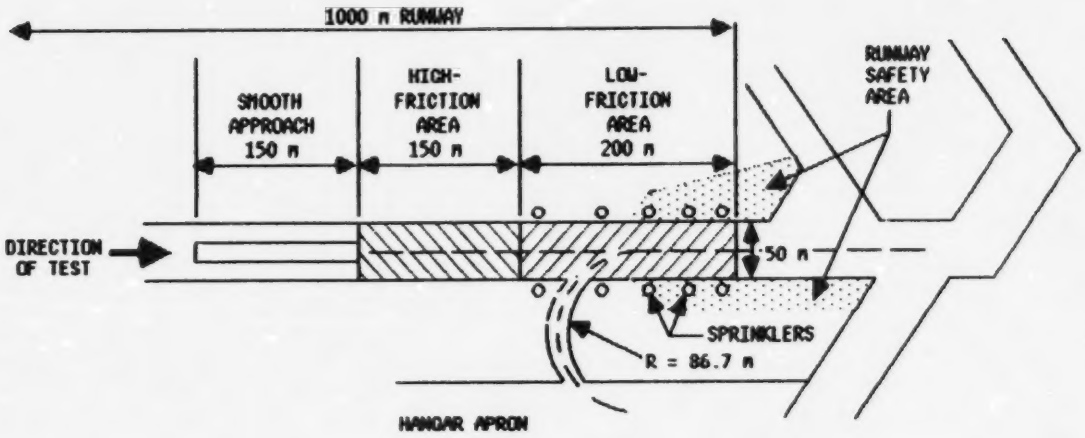


Figure 3/ MTC Commercial Vehicle Test Facility (Centralia)

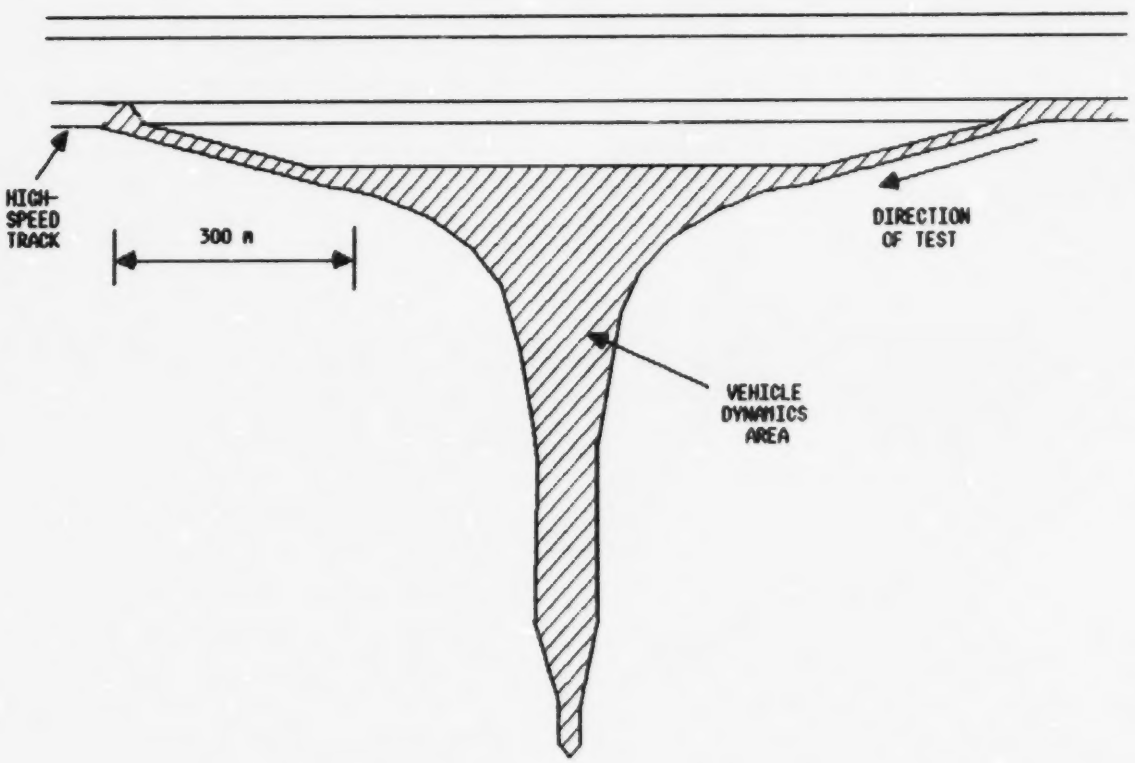


Figure 4/ Vehicle Dynamics Area, Transport Canada Motor Vehicle Test Centre (Blainville)

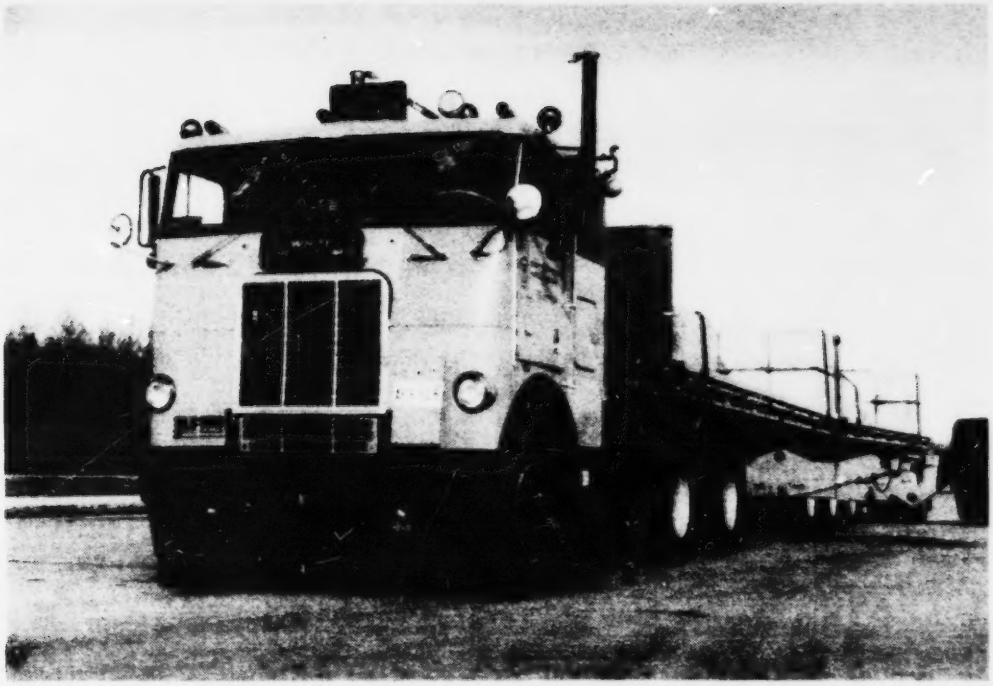


Figure 5/ MTC Freightliner

Figure 6/ MTC International

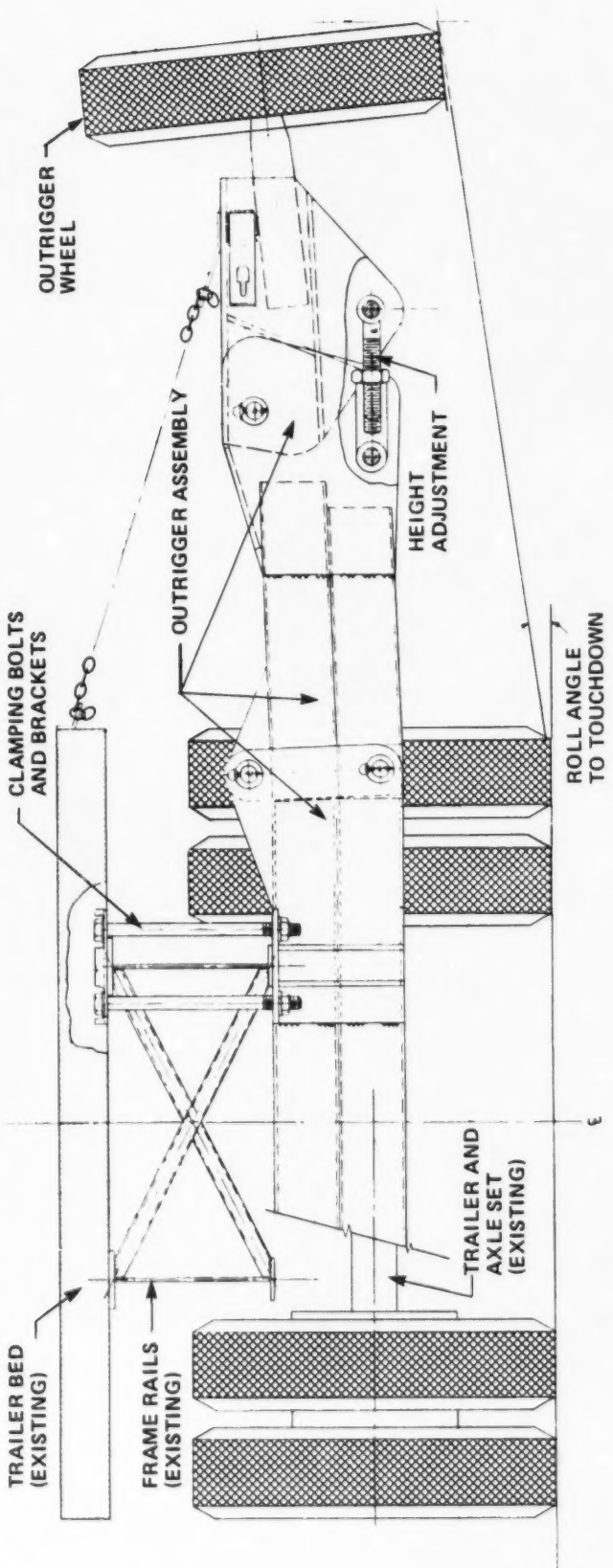


Figure 7/ Outrigger Assembly

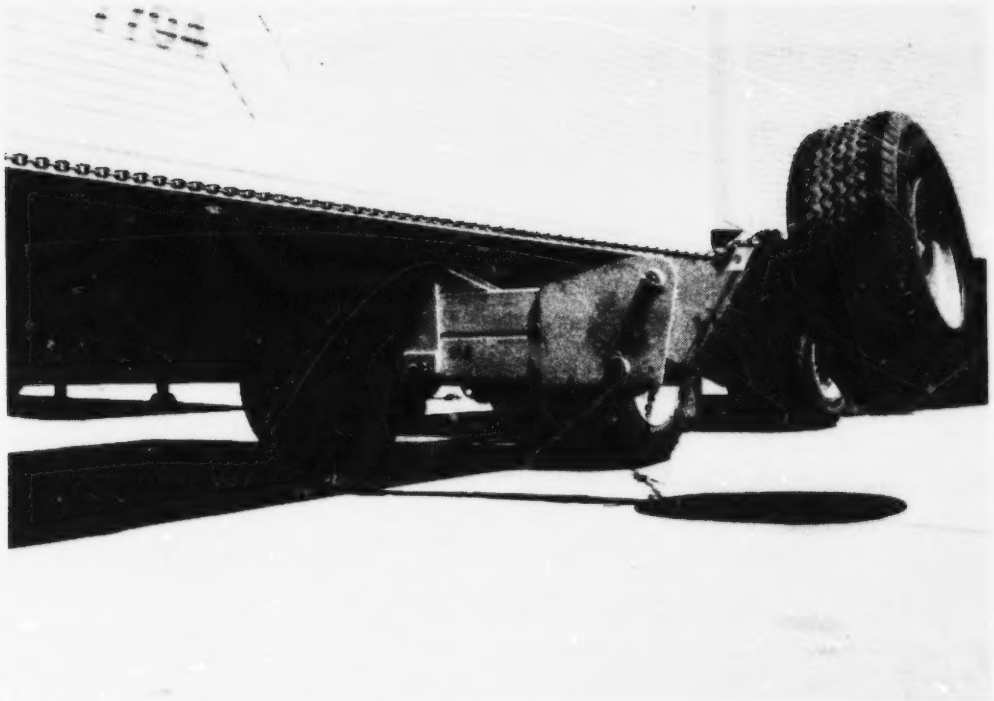


Figure 8/ Underslung Outrigger Installation

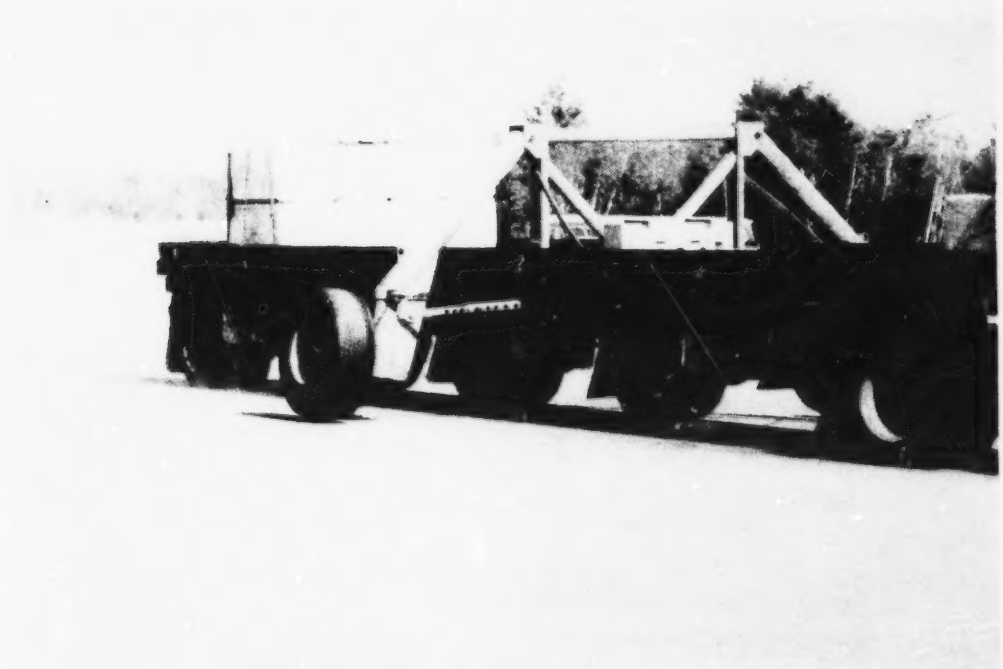


Figure 9/ Frame Outrigger Installation

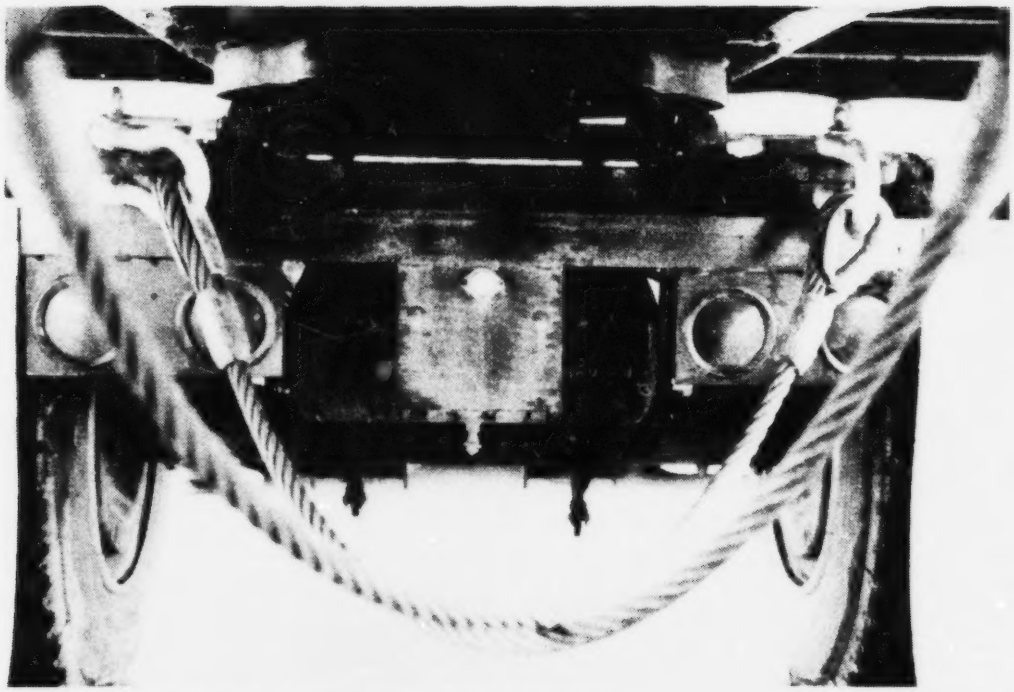


Figure 10/ Safety Cable Installation

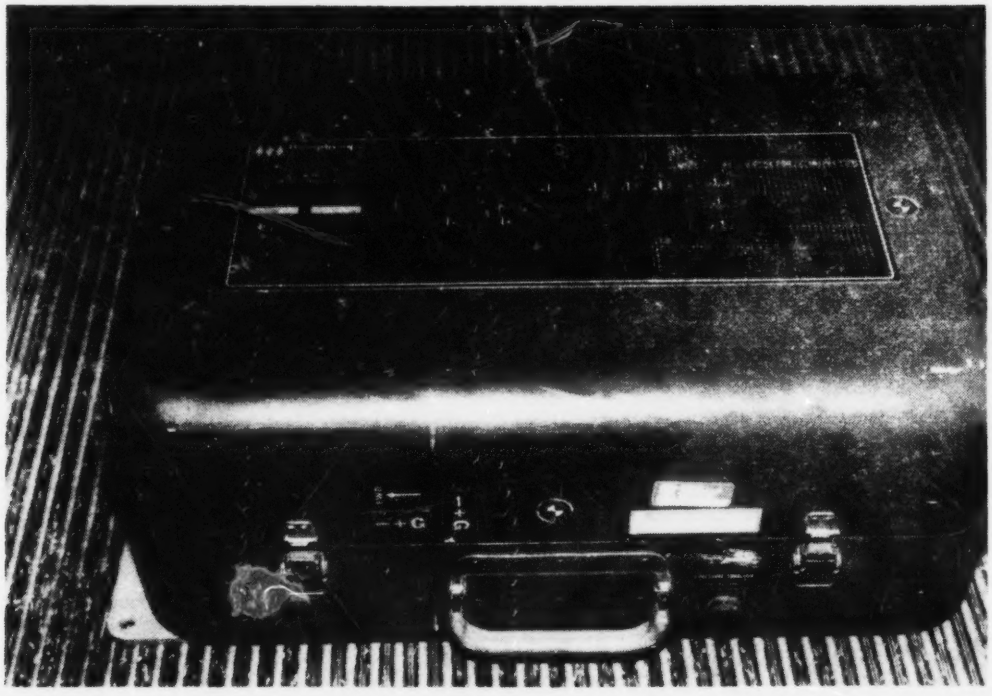


Figure 11/ Gyro Package

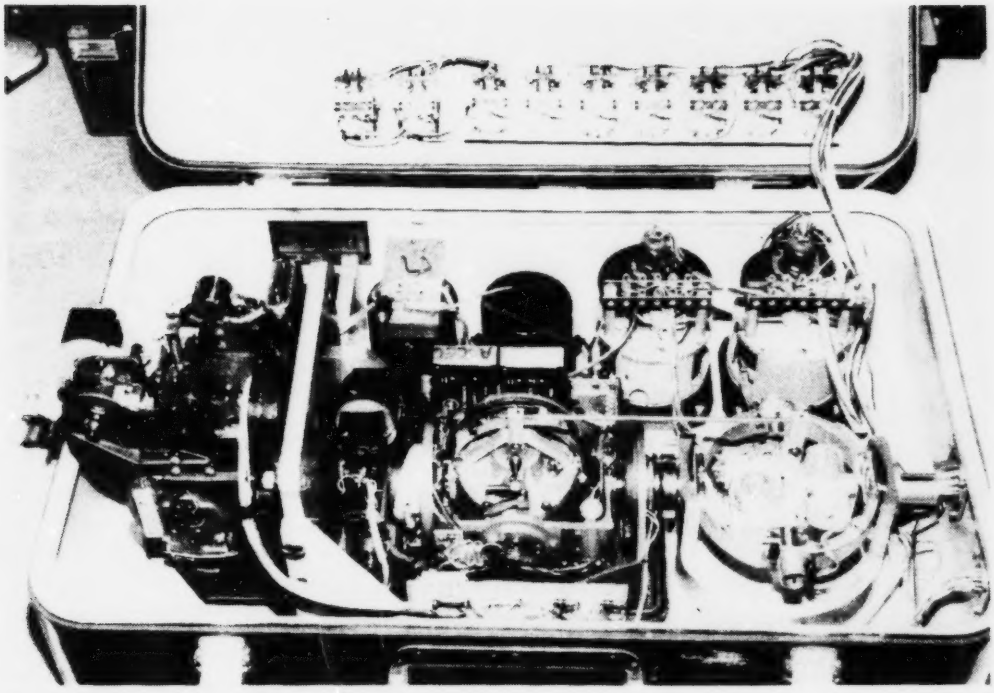


Figure 12/ Gyro Package

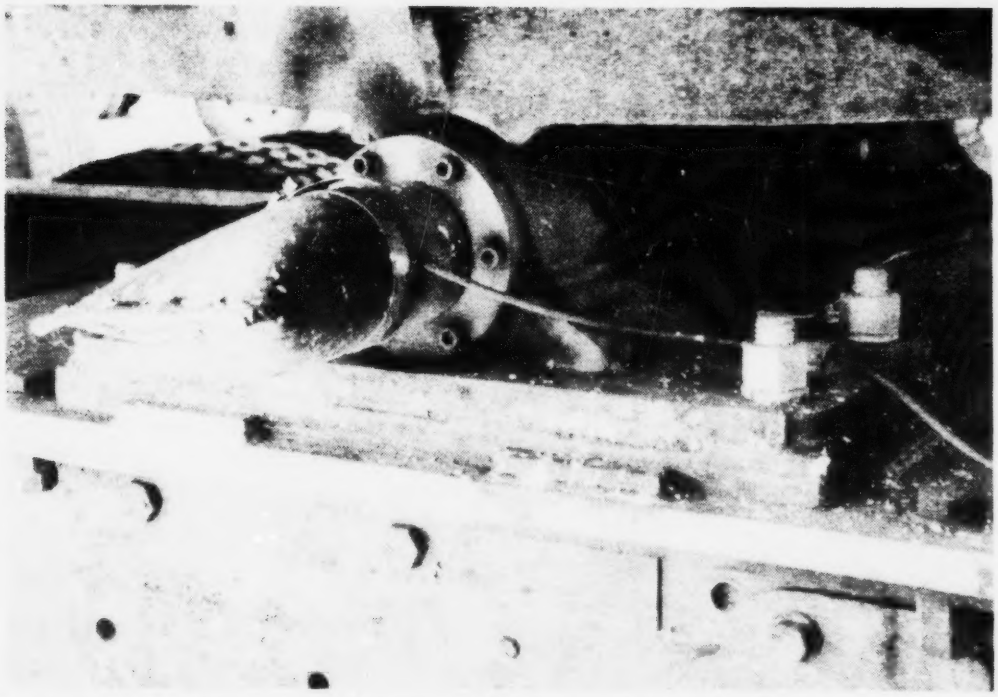


Figure 13/ Load Measuring Fifth Wheel Installation

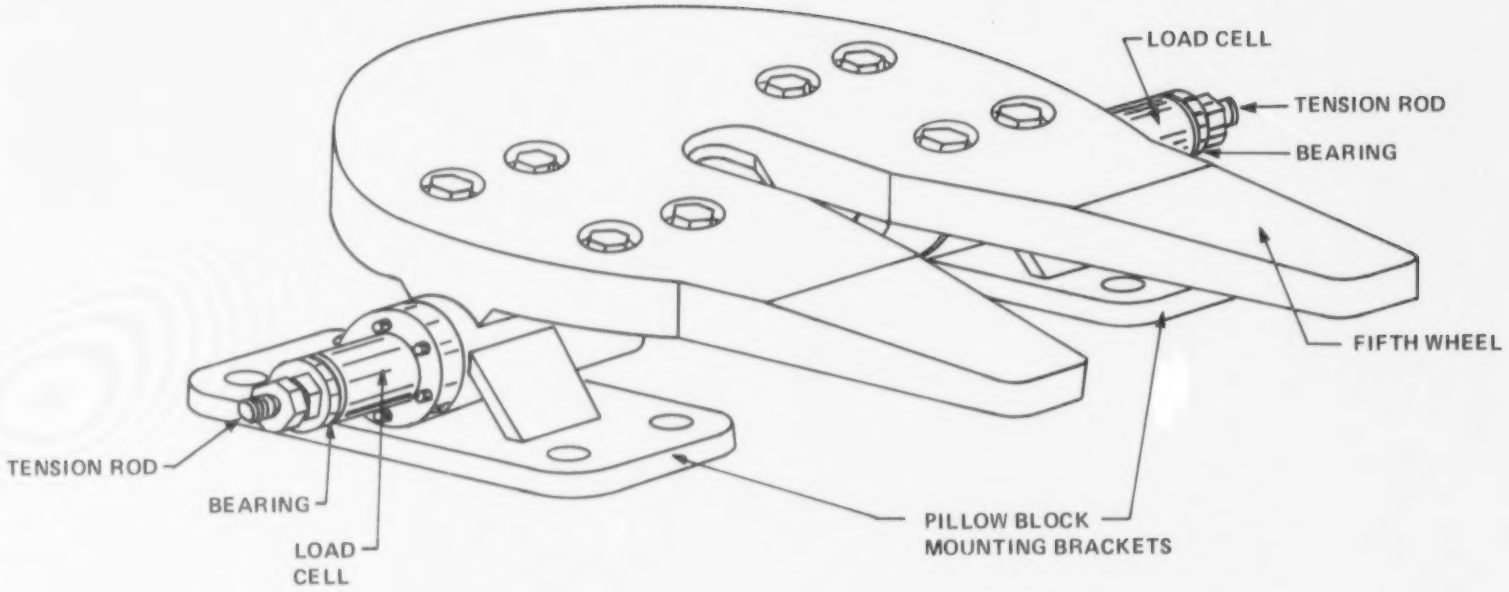


Figure 14/ Load Measuring Fifth Wheel Assembly

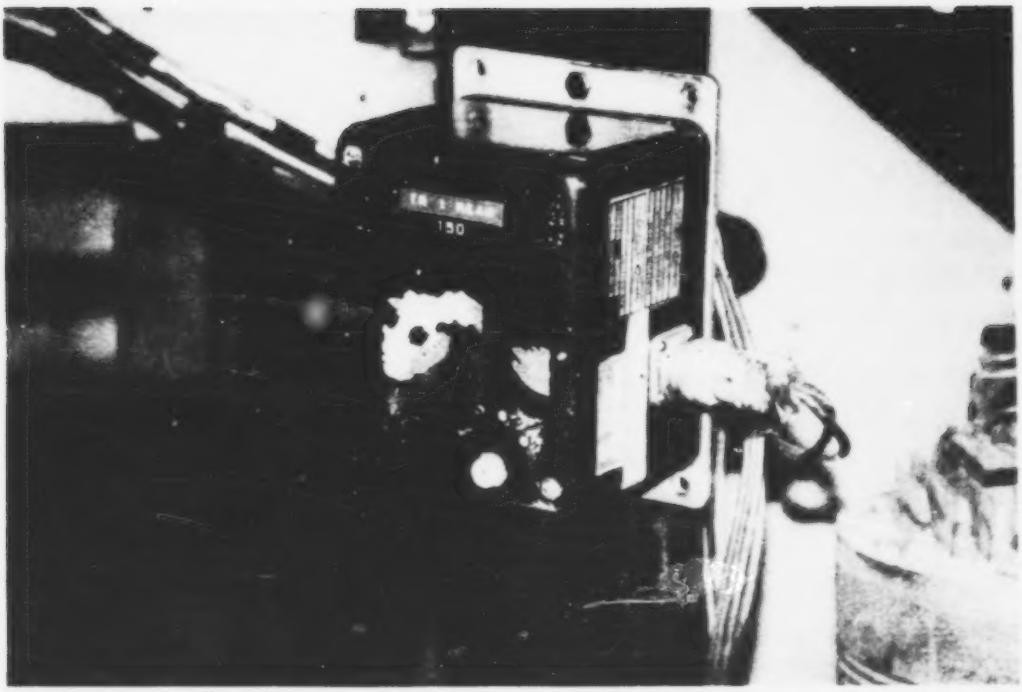


Figure 15/ Pull-Cord Transducer for Lead Trailer Articulation

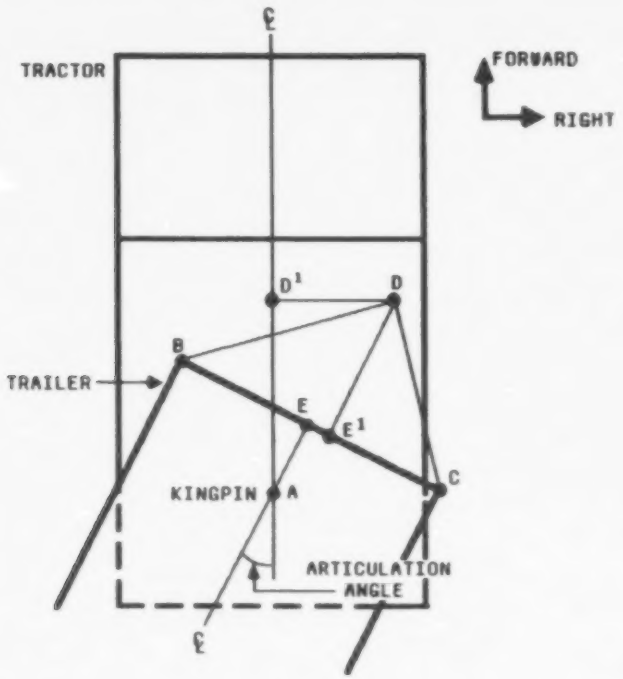


Figure 16/ Articulation Angle Calibration

Figure 17/ Trailer Articulation Measurement

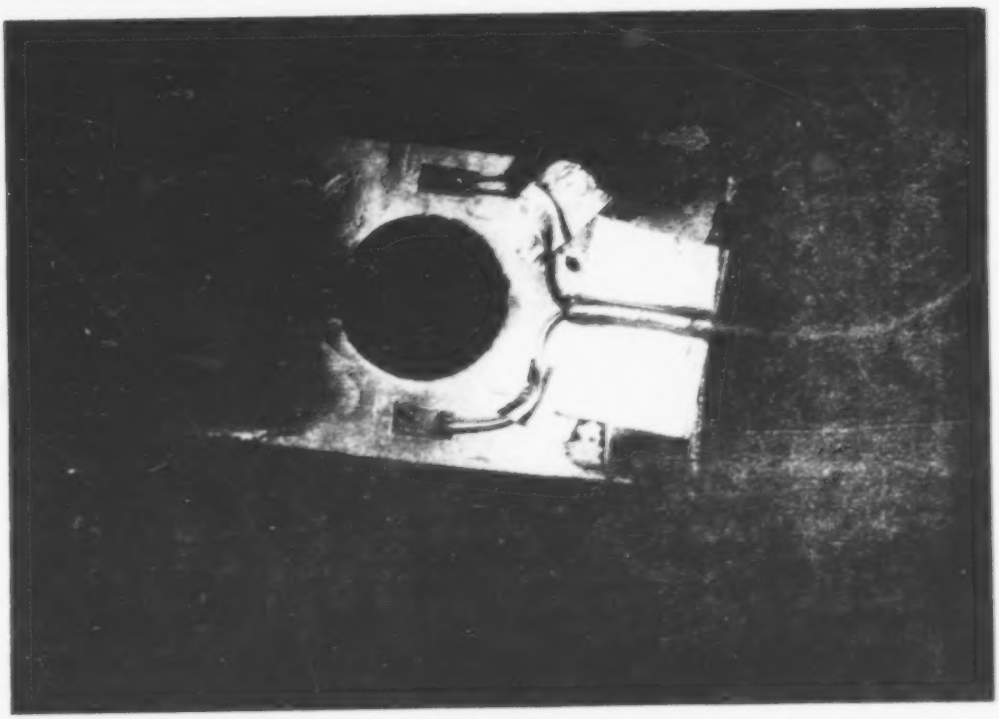


Figure 18/ Outrigger Touchdown Indicator Strain Gauging

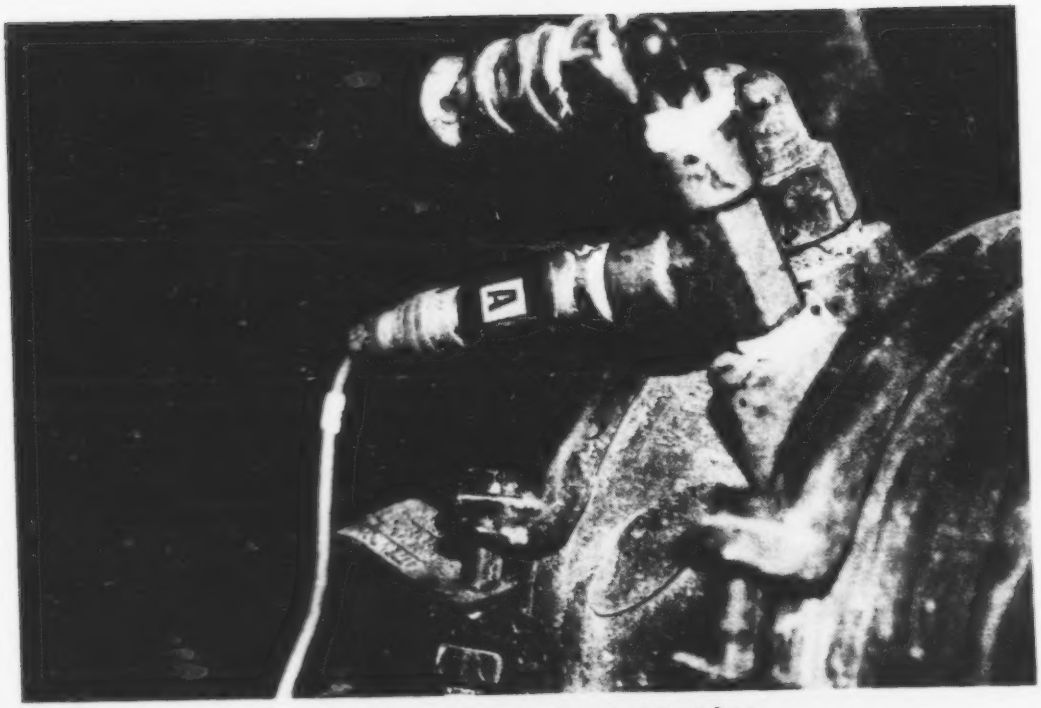


Figure 19/ Pressure Transducer Installation

Figure 20/ Trailer Instrumentation Package

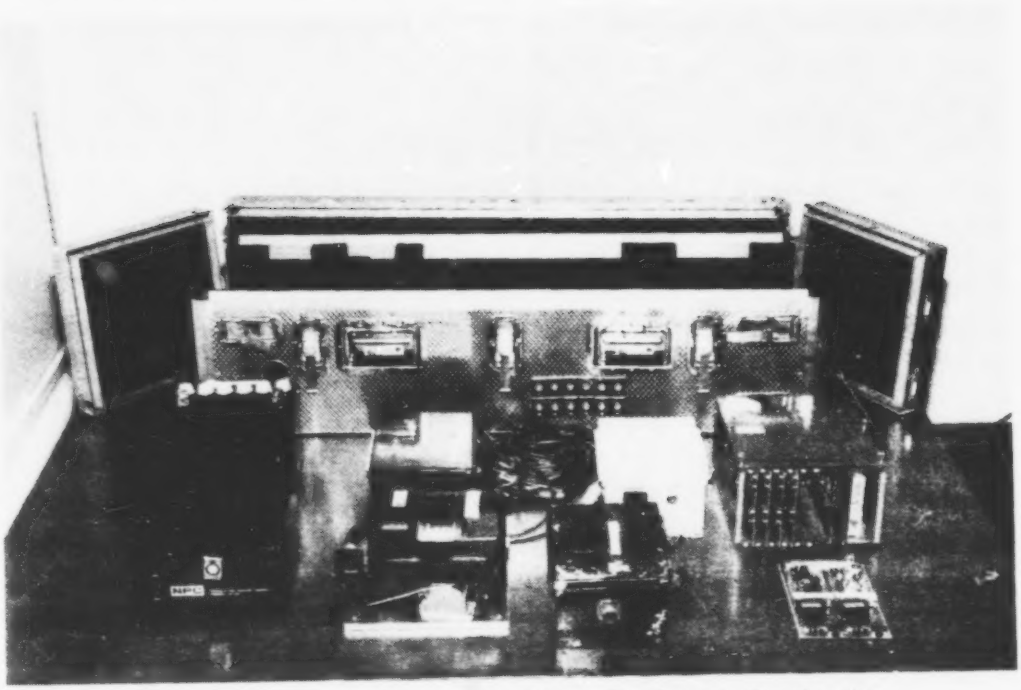


Figure 21/ Trailer Instrumentation Package Contents

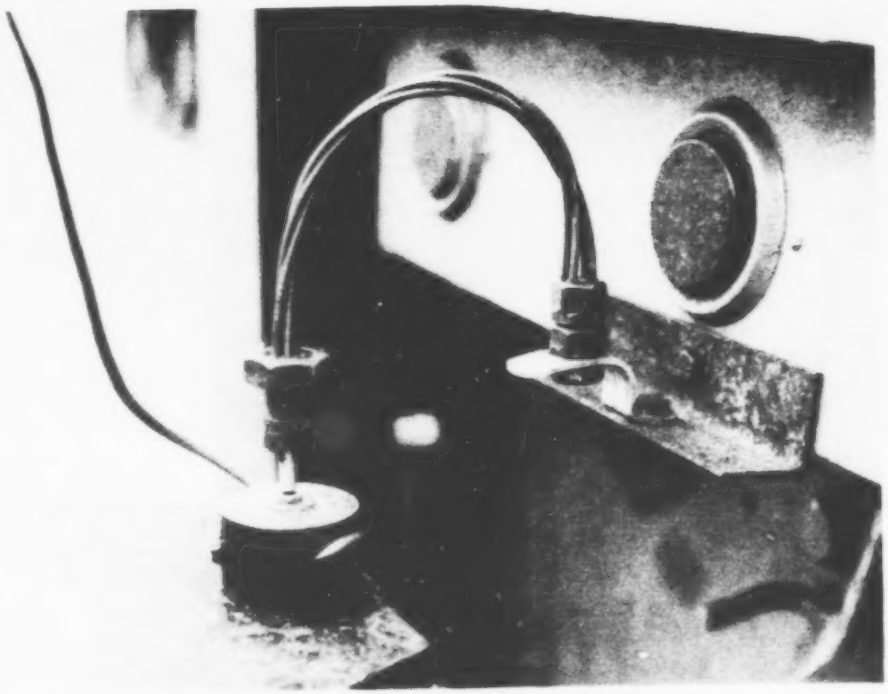


Figure 22/ A-Dolly Hitch Angle Measurement

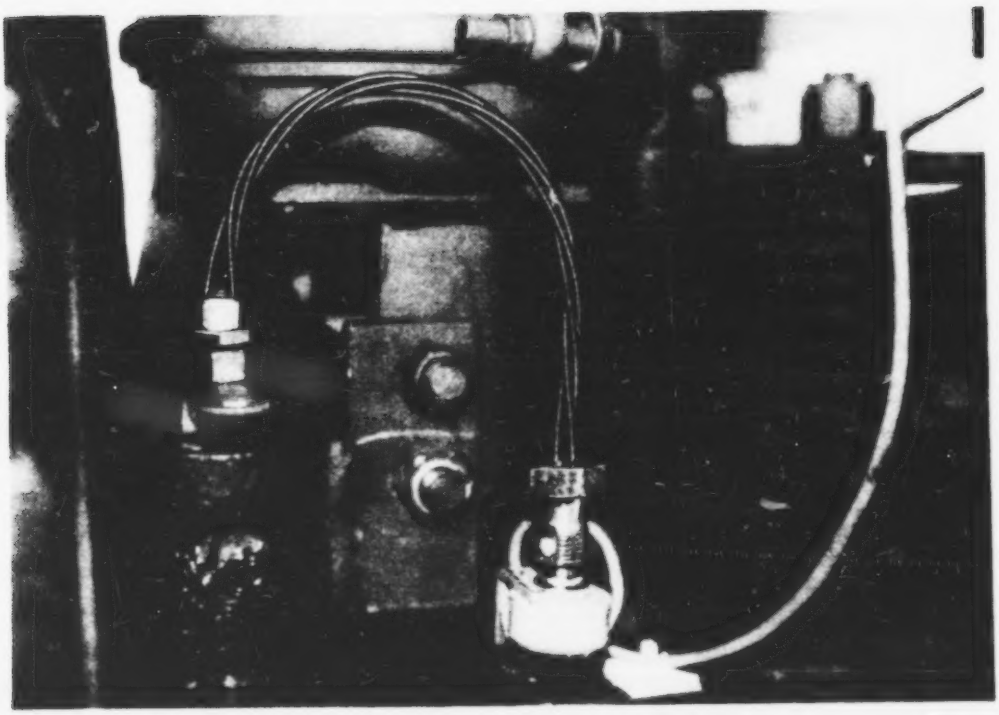


Figure 23/ B-Dolly Steer Angle Measurement

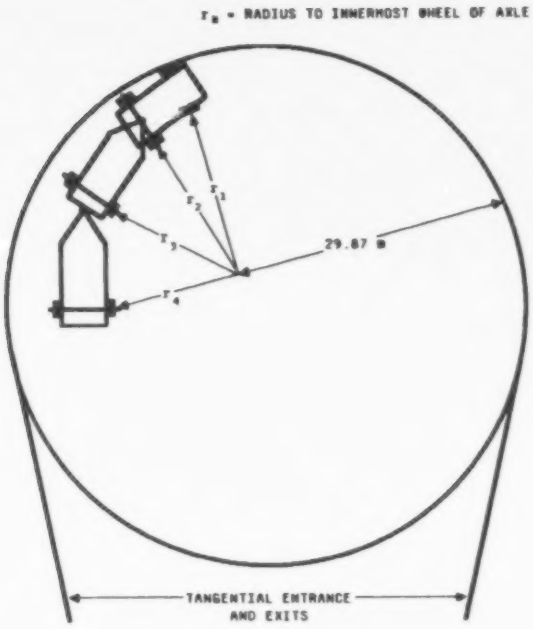


Figure 24/ Offtracking Course

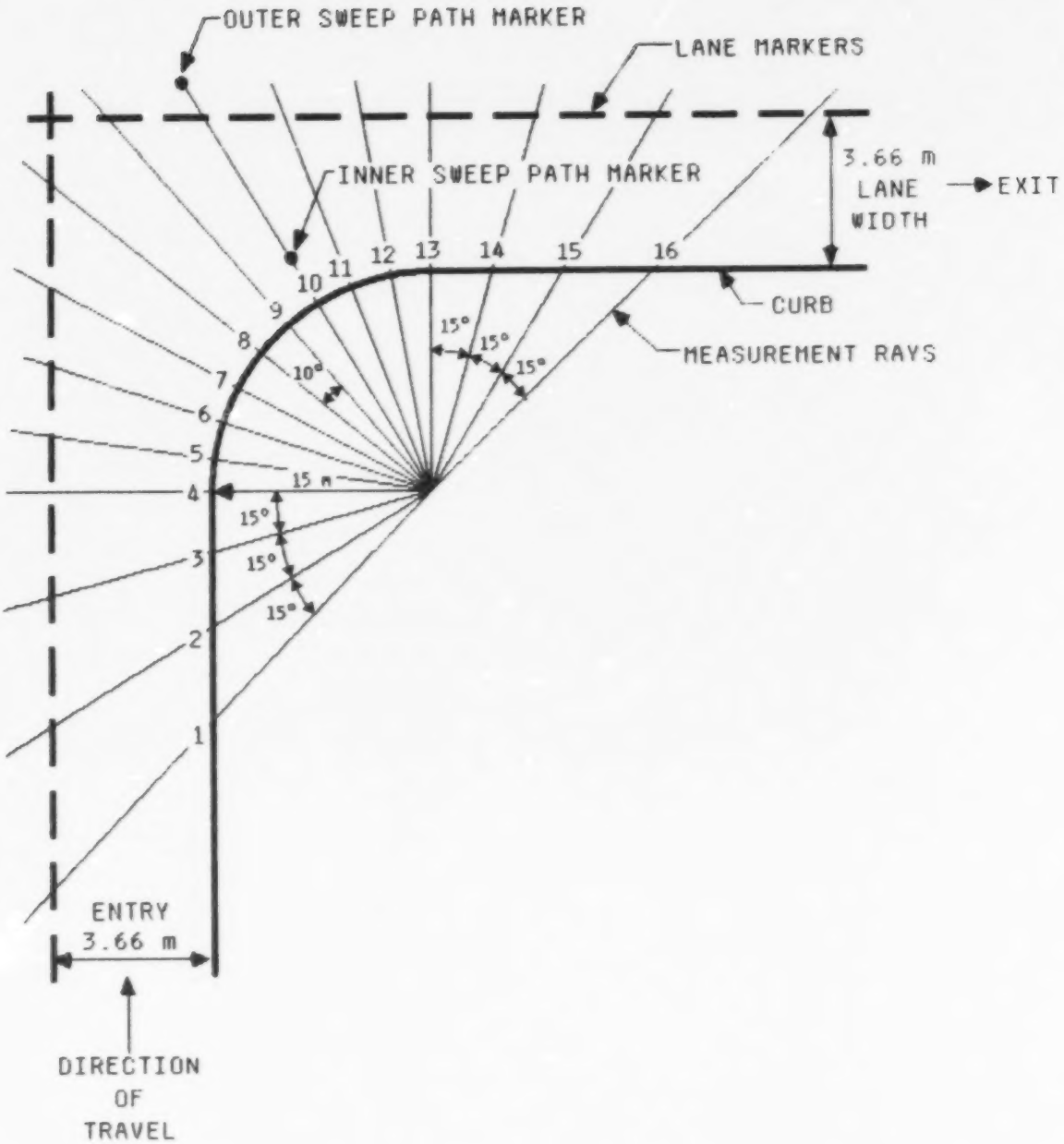
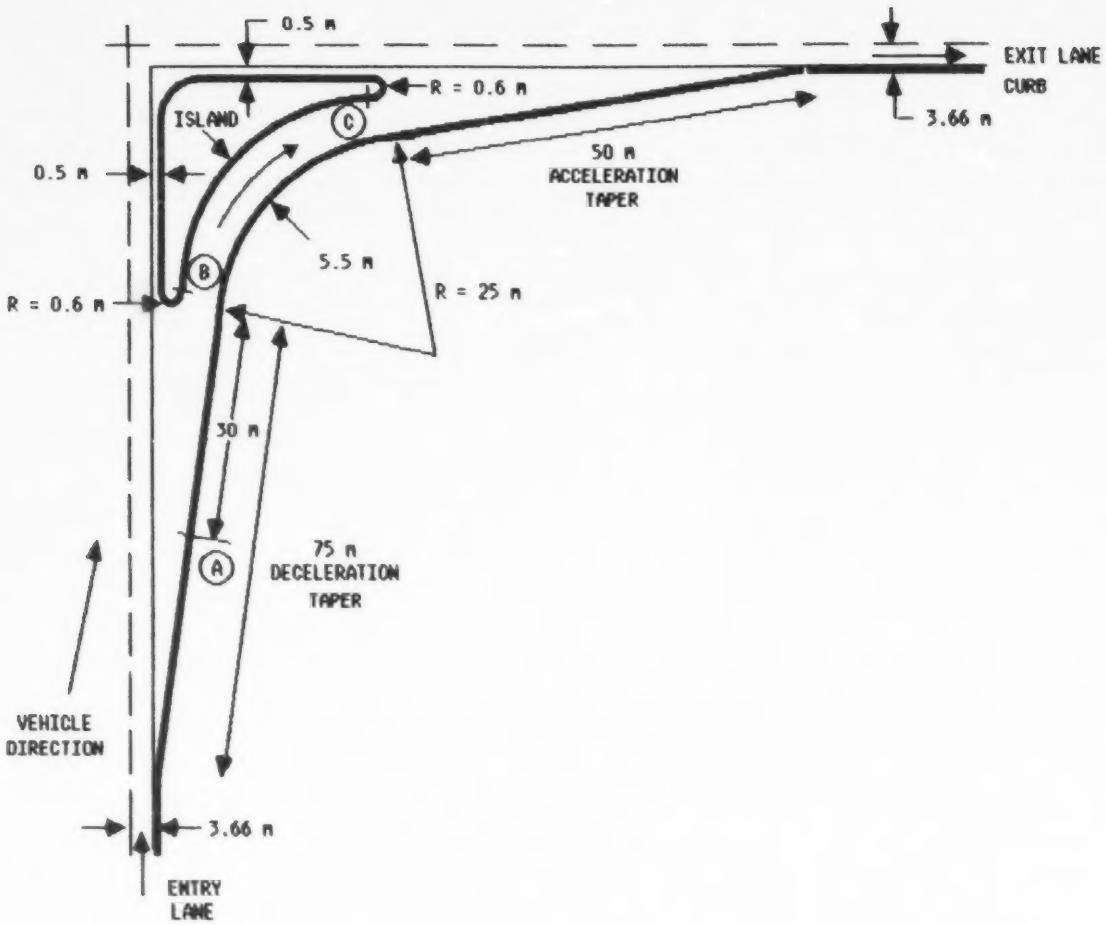
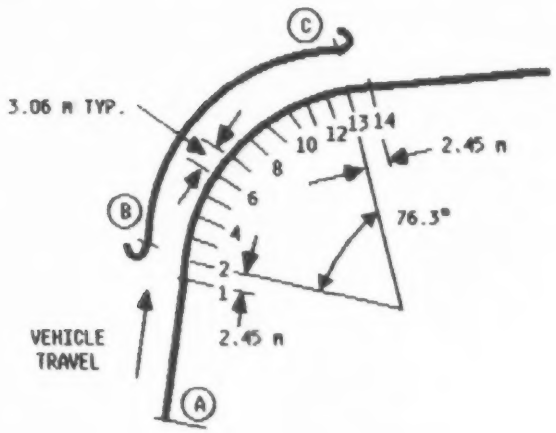


Figure 25/ Right-Hand Turn Course



(a) Geometry



(b) Measurement Reference Points

Figure 26/ Channelized Right Turn Course

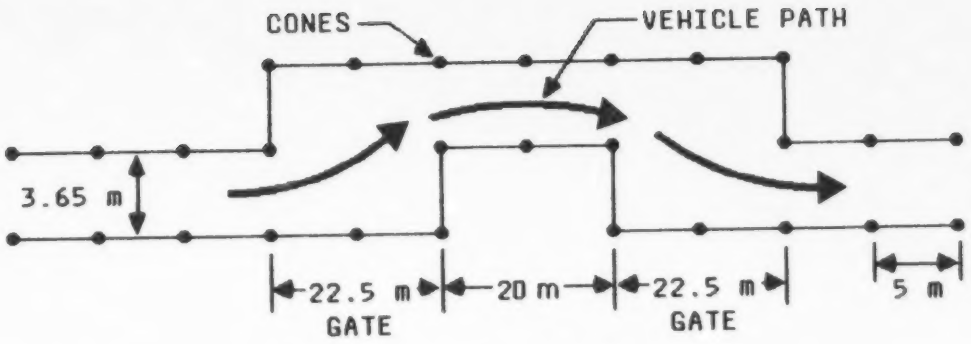


Figure 27/ Evasive Manoeuvre Course

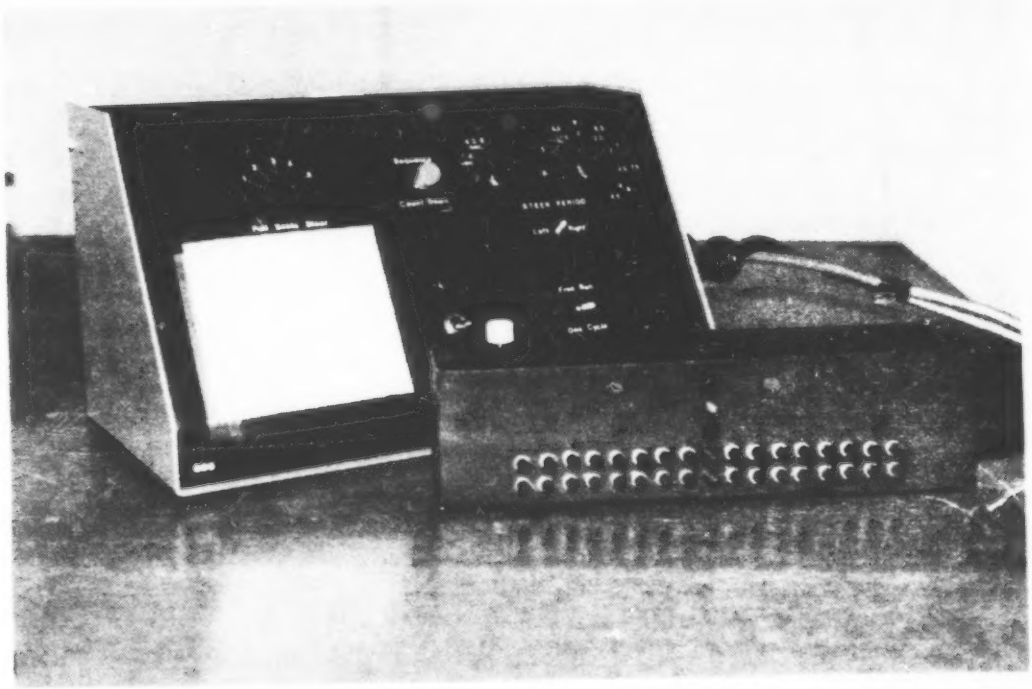


Figure 28/ Steer Period Generator

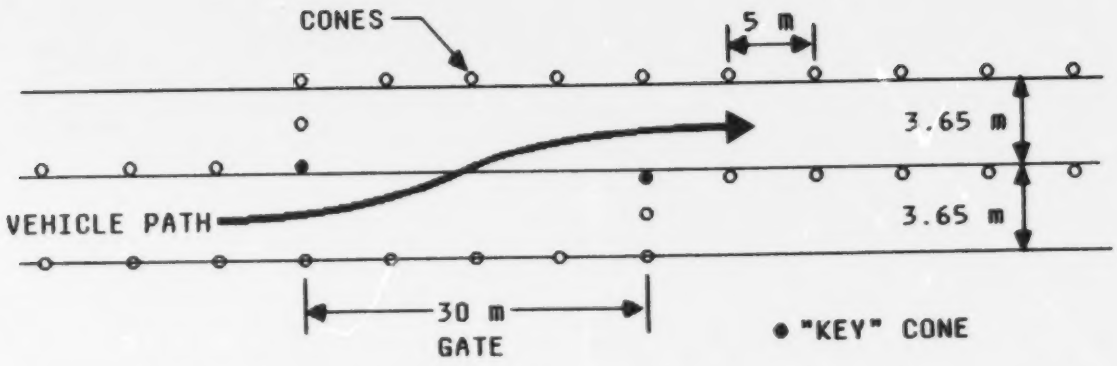


Figure 29/ Lane-Change Manoeuvre Course

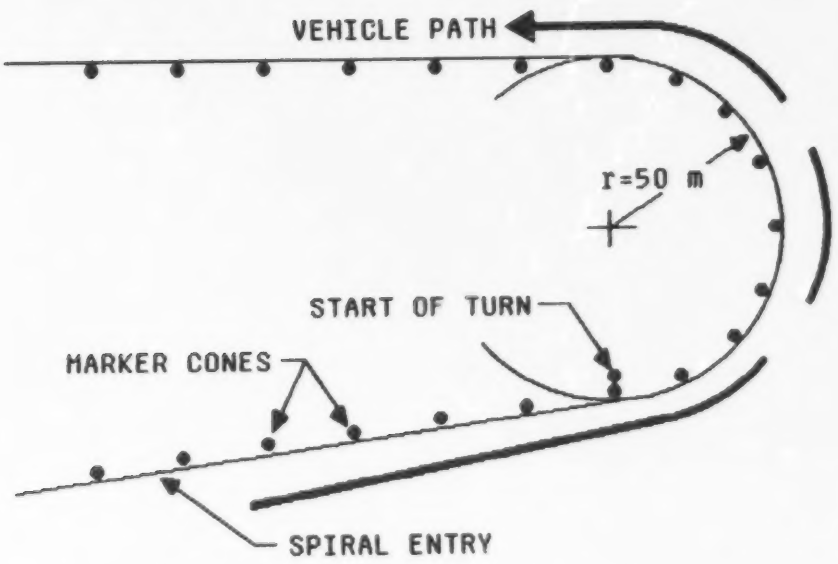


Figure 30/ Steady Circular Turn Course

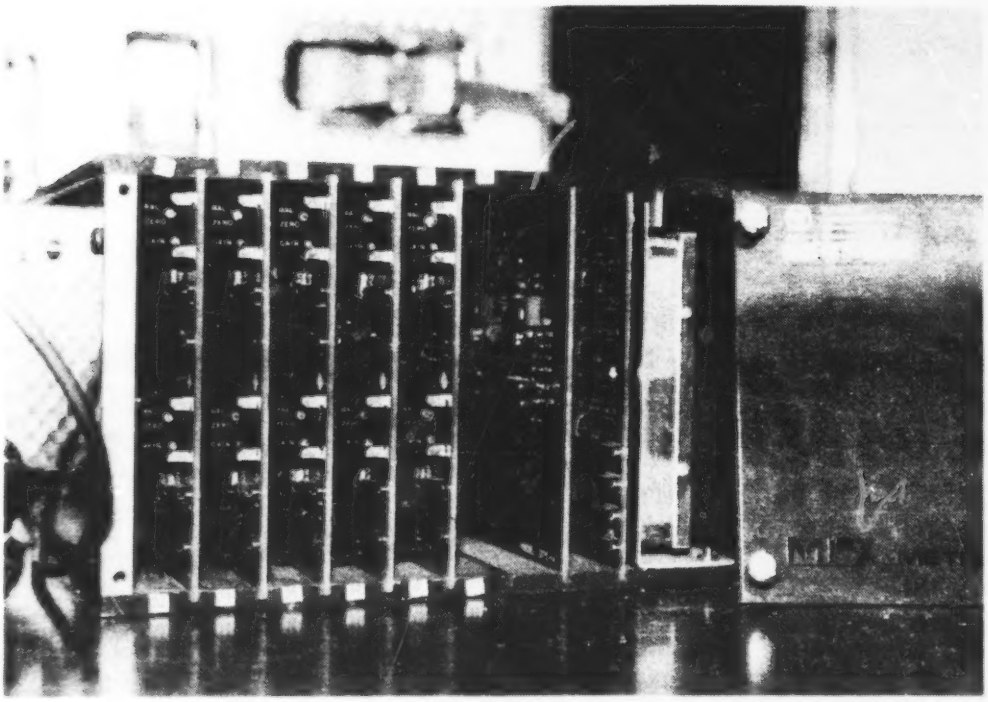


Figure 31/ Multiplex Unit with Signal Conditioning Card

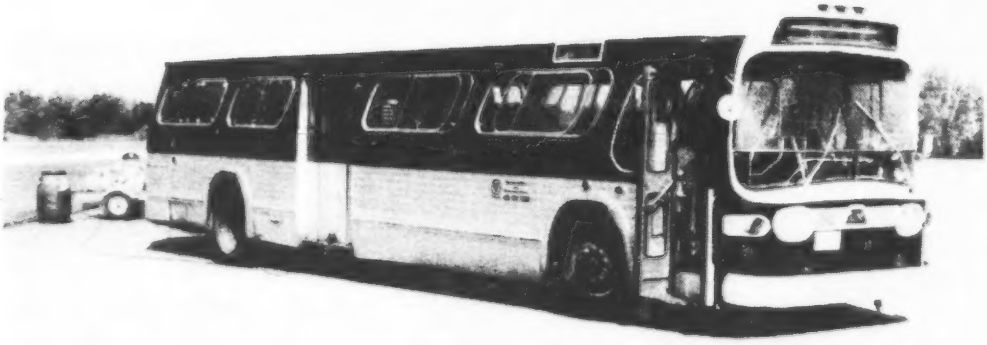


Figure 32/ Mobile Ground Station

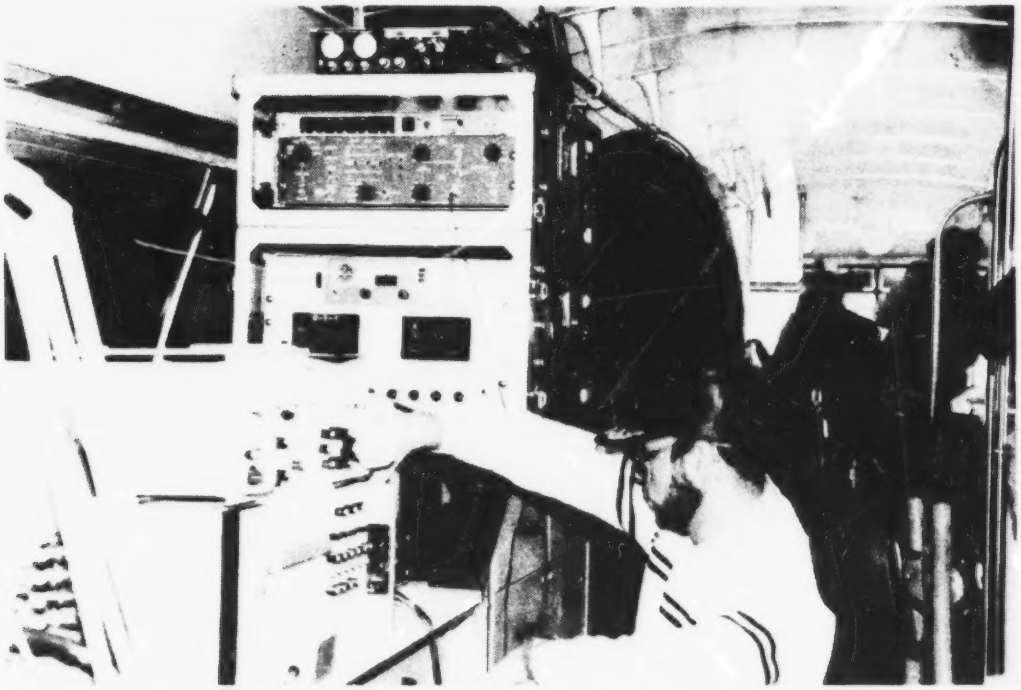


Figure 33/ Ground Station Equipment

Figure 34/ Computer in Ground Station

Figure 35/ Recording a Run

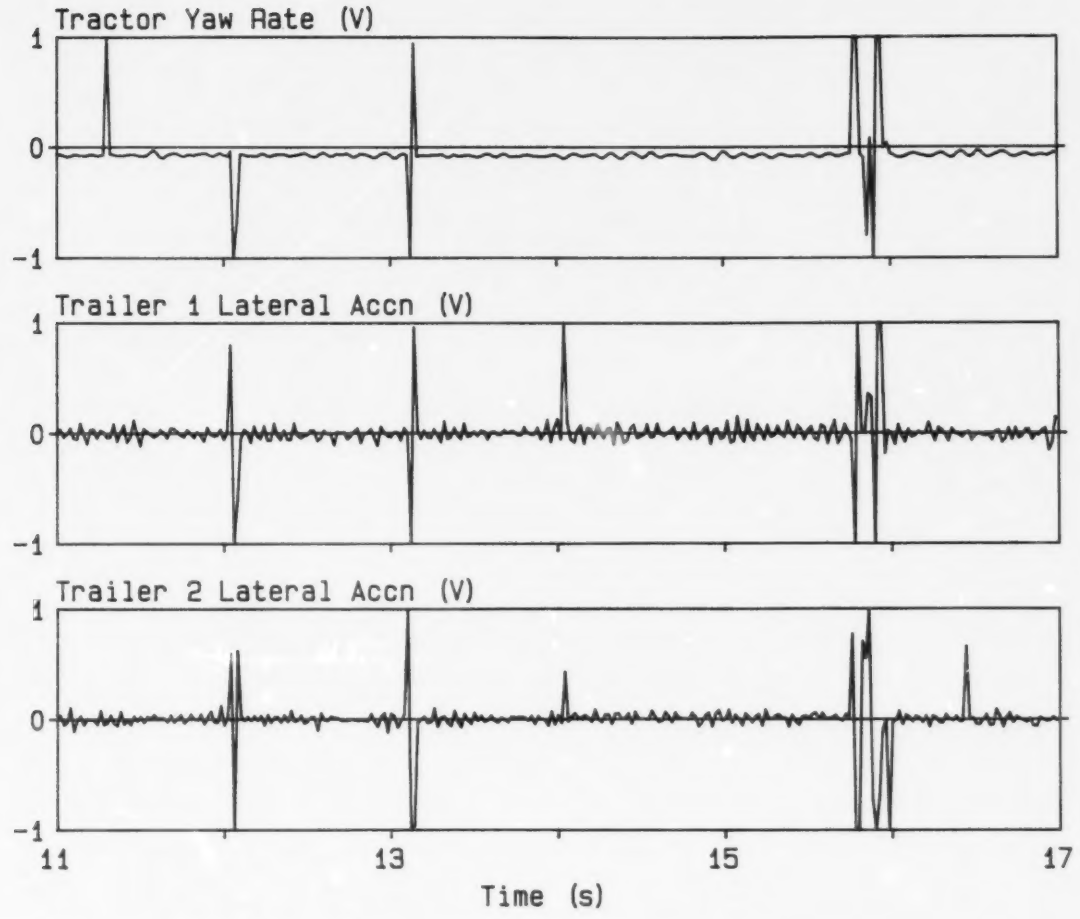


Figure 36/ Telemetry Dropouts in Data Record

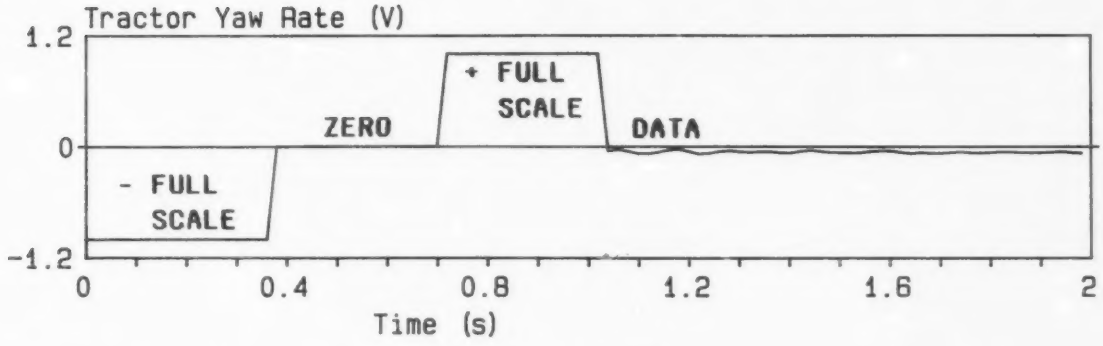


Figure 37/ Electronic Calibration Sequence

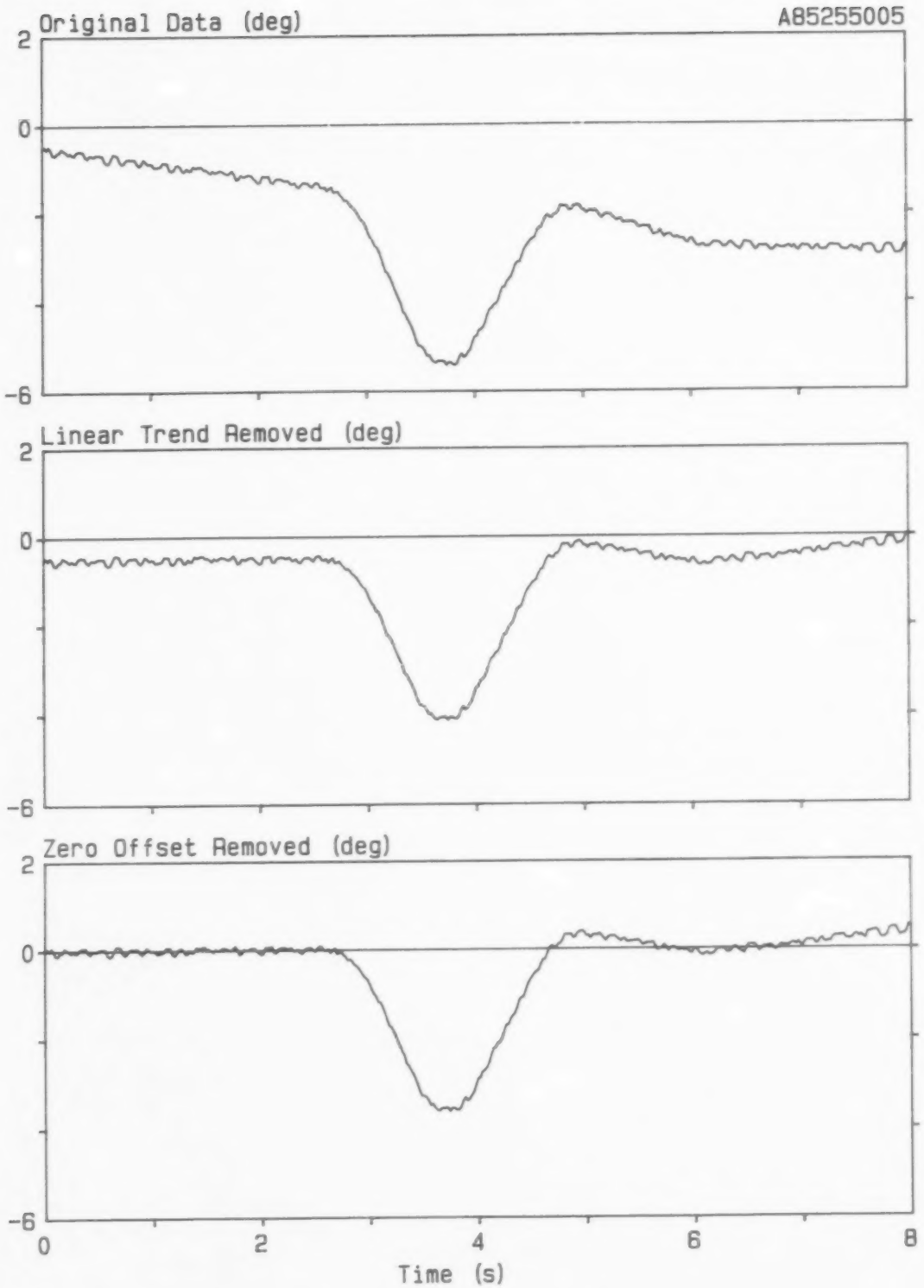


Figure 38/ Data Detrending

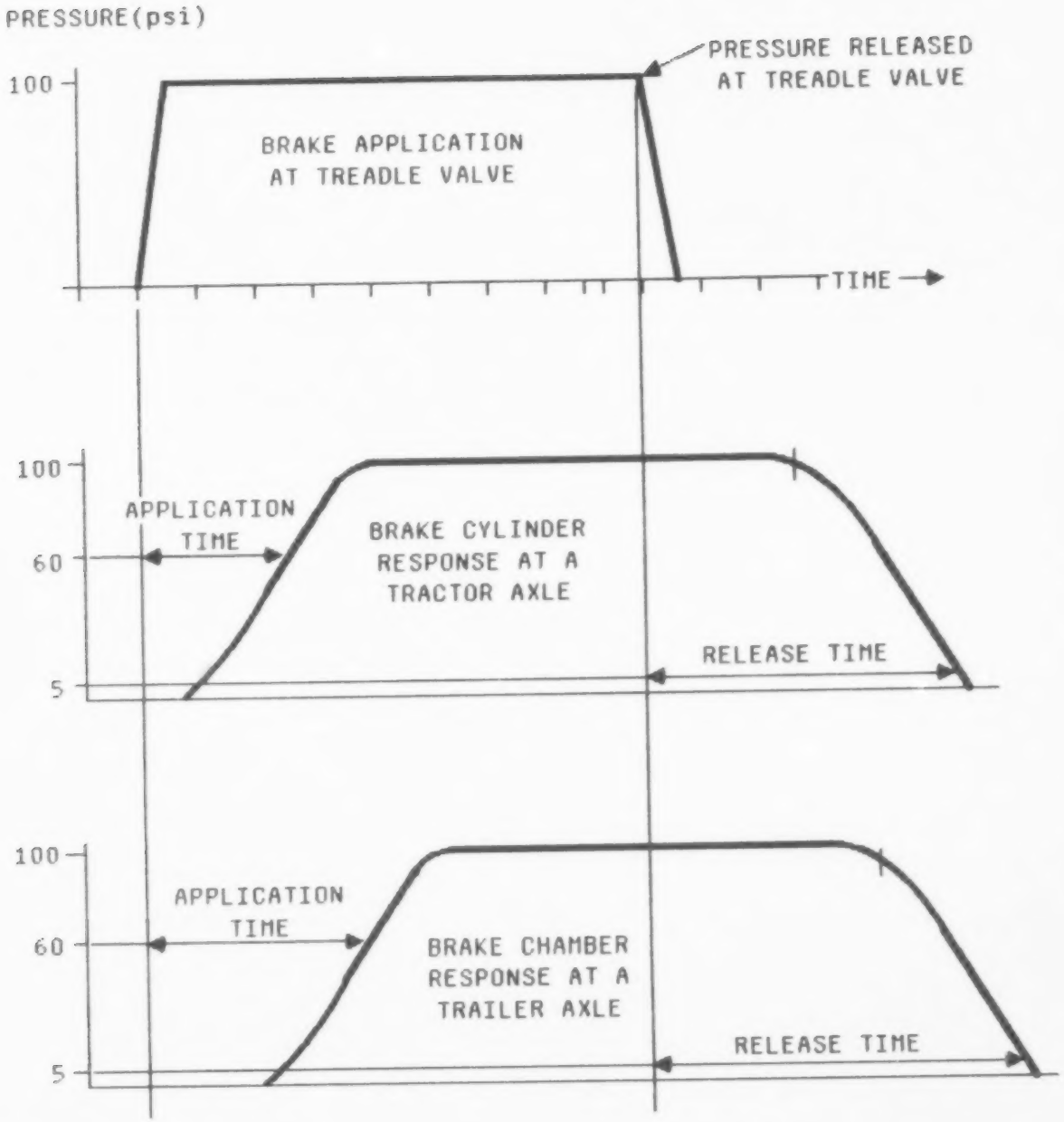


Figure 39/ Typical Brake Pressure Time History

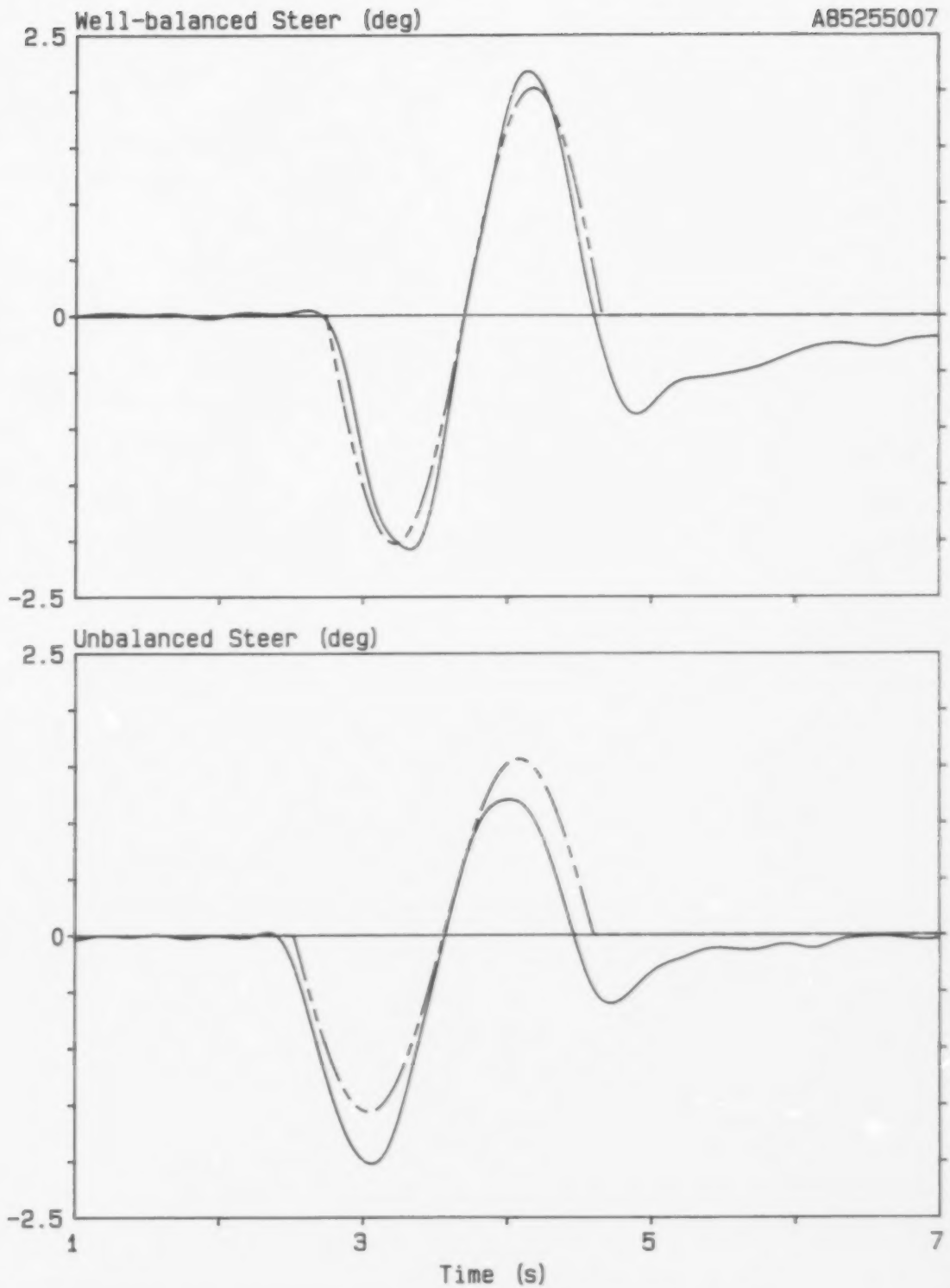


Figure 40/ Sinusoidal Steer with Fitted Sine Wave

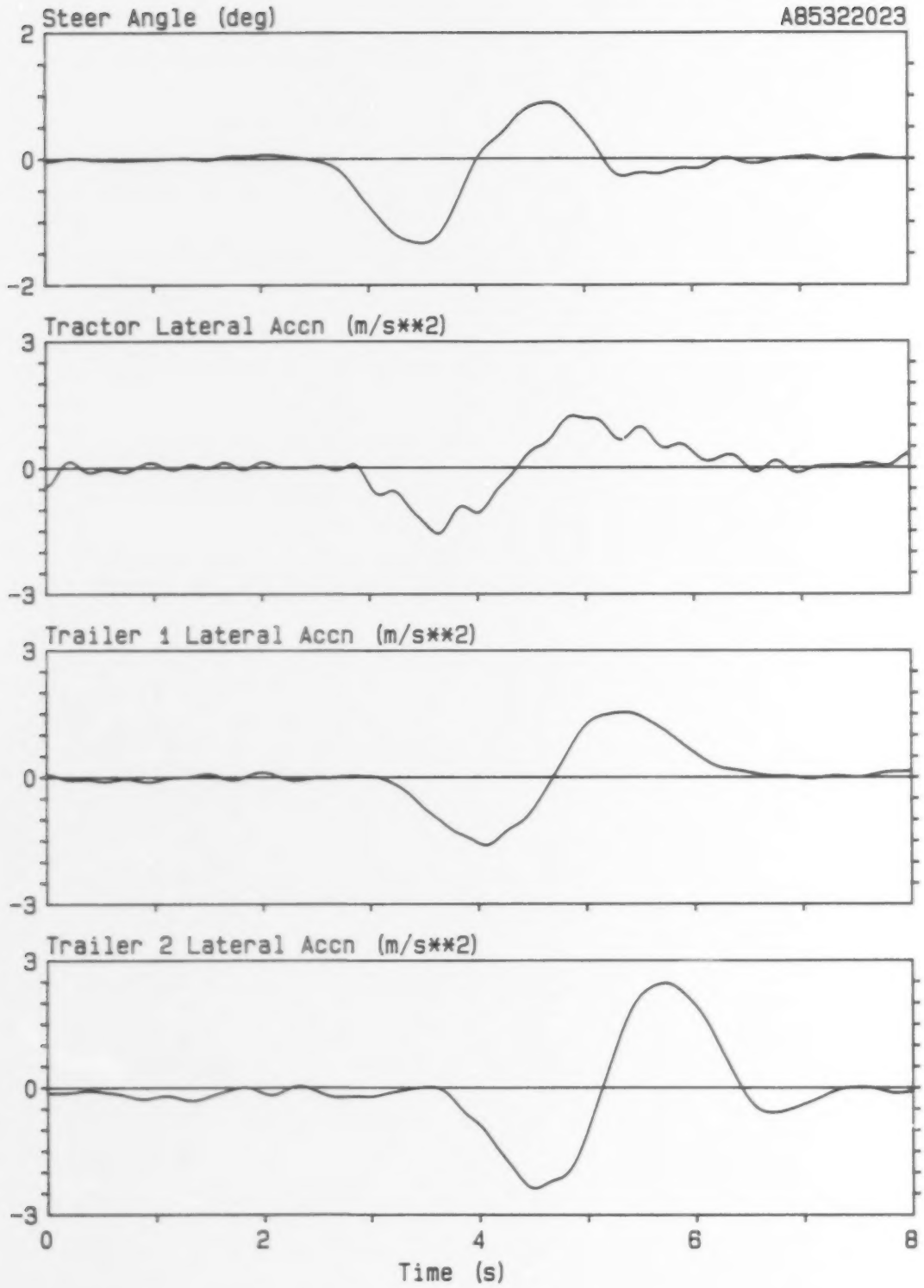


Figure 41/ Lateral Acceleration Gain